THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

The One Hundred and Eighteenth General Meeting of the Institution of Petroleum Technologists was held at the Royal Society of Arts, John Street, Adelphi, London, on Tuesday, March 12th, 1929, Mr. Ashley Carter, in the absence of the President, occupying the Chair.

The Chairman, at the opening of the meeting, stated that the President had requested him to express his regret that he was unable to be present.

Unfortunately the author of the paper to be read, Mr. G. Heseldin, was not in this country, but Mr. A. E. Chambers had very kindly undertaken to read the paper on his behalf.

The following paper was read by Mr. A. E. Chambers :—

Drilling for Oil with the Diamond Drill.

By G. Heseldin, M.Sc., Assoc.M.Inst.C.E. (Associate Member).

The paper deals with the adaptation of the diamond drill for the drilling of " wildcat " test wells in the search for petroleum, with special reference to recent operations in India (Figs. 1 and 2).

The need for more accurate geological information than it was possible to obtain with either the standard tool or rotary systems of drilling was the chief reason why the diamond drill, which had been so successful in the metal mining industry, was introduced for these wildcat drilling operations.

The *raison d'être* of the diamond drill is, of course, its ability to obtain a continuous core of the formations penetrated, and here it stands supreme. The cutting is done by means of Brazilian black diamonds, which are the hardest substance known, and until any other system can run a diamond bit successfully it can never obtain the complete geological information that is obtained with the diamond drill. The diamond drill can core the hardest formations as well as the soft ones.

The continuous core, which is obtained with the diamond drill, gives much more reliable and accurate data of the formations and structure being tested than any other drilling system at present in use in the oil industry. The core gives much more information than merely indicating the nature of the ground being drilled

fossils which may be embedded in the core furnish means of correlating the beds and determining the age of the formation, and also reliable rock samples for mineral analysis, so useful in correlations, can be obtained from the core. Bedding planes are clearly defined in certain rocks and furnish clues as to structural folding at depth. The porosity of a sand can be accurately obtained from the cores and the presence of oil or gas noted; the oil oozes out between the grains of an oil sand and gas bubbles can be clearly seen. The cores obtained with a diamond drill are uncontaminated and are not burnt or distorted in any way.

The diamond drill takes a continuous core, and the advantage of a continuous core over the occasional cores which are ordinarily taken with the rotary tools is very great, especially in areas in which the structure is not clearly indicated from the outcropping rocks. The whole history of underground conditions is revealed in the core, and changes are observed which might easily be passed unnoticed or be misinterpreted with occasional cores.

Again, zones of fracture can be noted from the cores in the softer rocks. The cores are shattered and slickensided, and the material is softer and full of fracture planes, thus the approach of a fault or overthrust can be detected and the unaccountable thickening or thinning of beds be explained.

Another important sphere of work for the diamond drill is the deepening of holes already drilled by other systems, the diameters of which have been reduced to such an extent that it is impossible to carry them any deeper. The diamond drill is able to deepen these holes considerably, because it requires much smaller casing clearances, and can drill with smaller bits than either the rotary or standard tool systems.

An attempt will be made to give a brief description of the diamond drill machine and equipment with its method of working, and also a description of the method employed in drilling wildcat wells with the diamond drill.

Description of the Diamond Drill.

The diamond drill machine is a self-contained unit consisting of the engine, transmission, hoist, and the rotating and feeding mechanism, all mounted on a common frame or base (Figs. 3 and 4.)

The machine occupies the centre of the derrick floor and is mounted on slide rails to enable the machine to be moved forward over the hole when drilling, and moved back out of the way when the drill rods are being run in or pulled out of the hole. This movement of the machine is effected by means of a hydraulic piston and cylinder situated underneath the machine.

FIG. 1.

THE DIAMOND DRILL IN ASSAM.

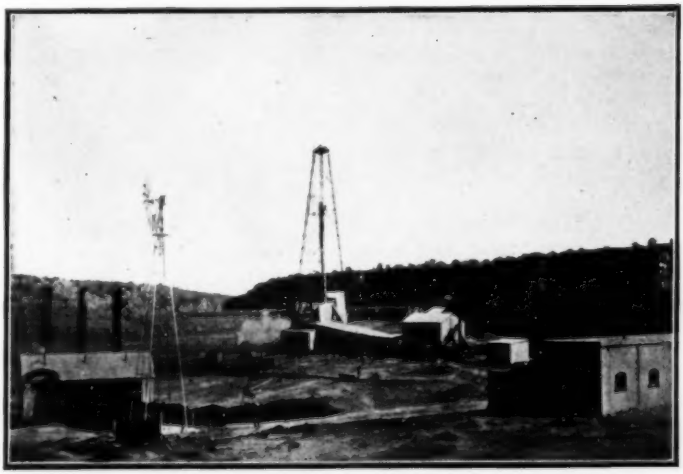

FIG. 2.

THE DIAMOND DRILL DRILLING A 6,000 FT. HOLE IN THE PUNJAB.

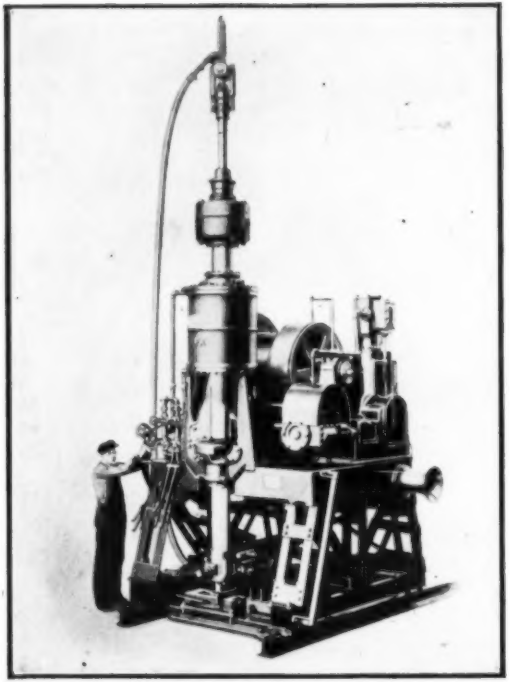

FIG. 3.
VIEW OF FRONT OF "F. K." DIAMOND DRILLING MACHINE.

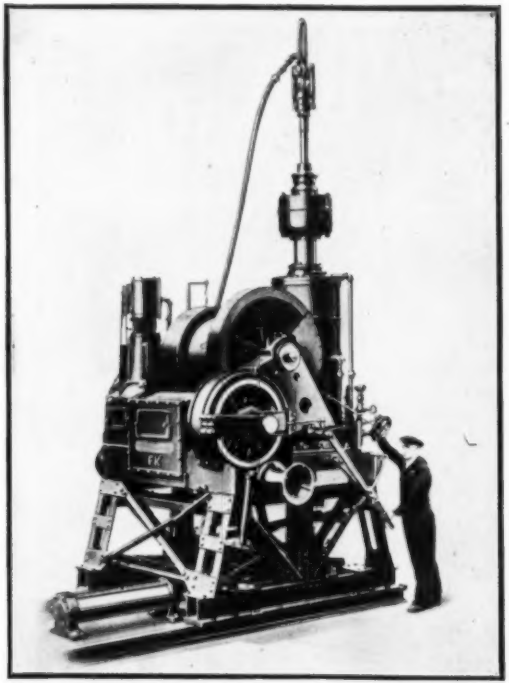

FIG. 4.
VIEW OF BACK OF "F. K." DIAMOND DRILLING MACHINE.

The description of the machine will be confined to the Sullivan, Type "FK" diamond drill, which is the largest diamond drill at present on the market, and which was designed specially for the oil industry. All smaller diamond drills of both this and other makes operate on the same principle, but the layout of the machine is rather different in the smaller sizes. This diamond drill machine is steam driven, but gasoline engine-driven machines are also built. The gasoline engine-driven diamond drill is very popular in the smaller sizes for structure testing work, where the drills are being constantly moved from one location to another.

Capacity.—The machine now being described is rated by the makers as capable of drilling a 4-in. diameter hole to 5,000 feet, and setting 4-in. casing at 4,000 feet. For mineral prospecting work, using smaller bits, the machine is rated for a depth of 7,000 feet. The machine will handle 12-in. to 14-in. fish-tail or rock bits at the surface.

The Whitehall Petroleum Corporation deepened a hole from 4,400 feet to 6,007 feet in the Punjab, India, with this machine. The diameter of the bit was $3\frac{1}{16}$ in. o.d. and the diameter of the core obtained was 2 in.

The hole was reamed out to a diameter of $5\frac{1}{2}$ in. with diamond reaming bits down to a depth of 5,311 feet, and a string of $5\frac{1}{2}$ in. o.d. seamless inserted joint casing was landed at this depth. The weight of this casing string was approximately 34 tons. At the time of drilling (Spring of 1925) this was the deepest hole that had ever been put down with the diamond drill in the search for oil. As far as the author is aware this record still remains unbeaten at the present time.

The Engine.—The engine is of rather an unusual type, consisting of two simple cylinders mounted at right angles to each other, both connecting rods working on the same crank pin. The cylinders have a bore of 7 in., a stroke of 8 in., and are operated by balanced "D" type slide valves. The engine runs at a speed of 400 r.p.m., the maximum steam pressure being 150 lbs. sq. in. and the maximum horse power is 80. The engine is well balanced and runs smoothly. The steam cylinders are lubricated by means of a mechanical lubricator.

The engine has an enclosed crank case and all bearings and moving parts are lubricated either by means of splash lubrication or a forced feed supplied by an oil pump driven from the engine crank shaft. Numerous inspection doors are provided for access to various parts of the engine. Usually the diamond drill does not require a reversal of motion for its operation, but a reversing gear is now

FIG. 3. VIEW OF FRONT OF "F. K." DIAMOND DRILLING MACHINE.

FIG. 4. VIEW OF BACK OF "F. K." DIAMOND DRILLING MACHINE.

being fitted to this type of drill to facilitate the quick handling of the hoist and for freeing locked cones on a rock bit. The reversing gear is not fitted to the machine shown in the illustrations.

Transmission.—An enclosed gear box of the automobile type, containing hardened nickel-steel gears, gives a range of three rotating speeds and three hoisting speeds. The gears are changed by means of levers conveniently placed at the front of the machine, and run in oil. The bearings are lubricated by forced feed or splash lubrication, depending on their position. The gears are comparatively noiseless and are easily changed.

The machine is provided with two cat heads which can be thrown in or out of gear as required by means of a lever situated at the back of the machine. The gears for the cat-head drive are incorporated in the gear box.

Hoist.—The hoisting drum is 2 ft. 8 in. in diameter and 1 ft. 9 in. long, which is rather on a small side. Stands of 75 ft. of drill-rods can be handled with five lines of $\frac{7}{8}$-in. diameter rope, but, if more lines are strung, the length of the stands must be shortened or else too much line will be spooled on to the drum when the travelling block is run up into the derrick. The drum is driven by means of steel gears which are enclosed in a gear case.

The pinion gear is mounted on a pinion shaft which is driven from an extension of the gear-box clutch shaft by means of a dog clutch. Mounted on the pinion shaft is the pinion brake. The drum brake or main brake is placed at the opposite end of the drum to the gear wheel.

Bevel gear wheels are mounted on the sides of the main gear wheel and brake wheel respectively and engage with two bevel pinions fitted inside the drum.

The whole arrangement of pinion brake, gears, drum and drum brake form a type of differential gear. Thus, when it is desired to hoist with the machine, the drum brake is tightened down, the pinion brake released, and the engine throttle opened. By easing off the drum brake a definite amount, a precise load can be obtained beyond which it is impossible for the machine to pull, as should a greater load be encountered, the drum brake will slip, causing the drill rods to remain stationary. This is very useful in fishing, when the fish drags in the hole, or for pulling out the bit in caving ground, thus preventing the bit being pulled fast into a tight place.

For lowering, three systems can be employed. First, the drum brake can be used with the pinion brake tightened down. This is the system generally adopted for running the bit into the hole, and for running down the blocks when pulling out.

Secondly, the pinion brake can be used with the drum brake tightened down. This system gives a more sensitive and surer control than the first, and is used when running heavy strings of casing, for lowering the bit through ground that is liable to bridge, or when core has been lost, and it is believed to be holding up in the hole, and for any other situation where it is necessary to lower with caution and at a more or less uniform speed.

Owing to the comparatively high speed of rotation of the pinion brake wheel, this brake heats up fairly rapidly and cannot be employed continuously for long periods.

The third system of lowering is by using the compression of the engine as a brake, the lowering speed being regulated by means of a release valve placed on the engine steam inlet pipes between the throttle and the steam chests. With the machine in third gear a very slow and constant lowering speed can be obtained. This system is used when getting on bottom with a diamond bit and when fishing.

With the engine running at 400 r.p.m., rope speeds of 516, 298 and 100 feet per minute can be obtained by means of the three gears. The gears cannot be changed when the machine is in motion.

The hoist will lift a maximum load of 16,000 lbs. on a direct pull with a single line.

The hoist is lubricated on the Alemite system.

Rotating and Feeding Mechanism.—The drive rod, which holds the drill-stem or "Kelly," is actuated from the gear box by means of two sets of bevel gears and a horizontal shaft on which is mounted a dog clutch. The drive rod is octagonal in section and slides through one of the bevel gears mounted on a thrust bearing.

There are three speeds of rotation, a slow speed of 45 r.p.m., an intermediate speed of 137 r.p.m. and a fast speed of 238 r.p.m., all with an engine speed of 400 r.p.m. The slow speed is used for rock bits, especially those with the self cleaning type of cones, and large fishtail bits in tough ground, the intermediate speed is used for fishtail bits and rock bits in easier ground, and the fast speed is used for the diamond bits.

In addition to the gears, the ordinary engine throttle control gives a wide range of speed on each gear.

The drill stem is held in the drive rod by means of two chucks. The bottom chuck, which is the one principally used, consists of four hardened steel jaws which grip the rods by means of set-screws operating behind them. The top chuck is practically an automatic spider and consists of four jaws working in tapered slots controlled by a lever which hangs down the front of the machine. The top chuck prevents the drill rods flopping about in the drive rod, and is used in conjunction with the bottom chuck when it is required to

take a heavy pull on the rods with hydraulic cylinder. The top chuck can be used by itself when drilling deep holes with diamond bits.

The bore of the drive rod is 5-⅛ in., which will take all sizes of diamond drill rods, also 4-in. drill-pipe.

The drive rod is suspended on to the piston rod of the hydraulic cylinder by means of a totally enclosed heavy ball thrust bearing.

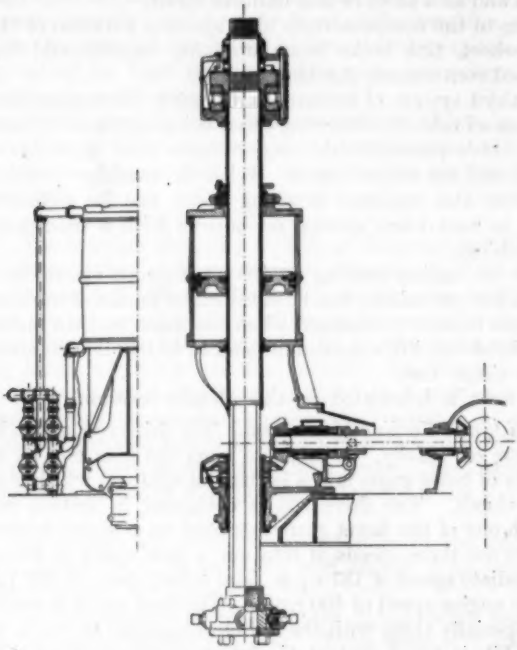

FIG. 5.

SECTION OF HYDRAULIC CYLINDER, "F.K." DIAMOND DRILL.

The hydraulic feeding device consists of a gun metal cylinder having an internal diameter of 24 inches. Working in this cylinder is a piston mounted on a hollow gun metal piston rod, inside of which is the drive rod. The piston is made water-tight by means of a couple of L leathers. The stroke of the piston is 24 inches, which is the feeding range of the cylinder.

A manifold of four valves (a pressure inlet and a waste valve on each side of the piston) controls the operation of the feeding device. A pressure gauge and a pet cock drain are fitted to the bottom cylinder cover (Fig. 5).

By means of the hydraulic cylinder a very sensitive and accurate feed can be obtained. This is essential when drilling with diamond bits as the stones in the bit are liable to be broken if the bit is fed too fast, or the feed is jerky.

The hydraulic feed is also ideal for rock bits as a sensitive and regular feed can be obtained. The load on the bit can be calculated at any time from the reading of the pressure gauge fitted to the hydraulic cylinder.

A special clear water pump is necessary to operate the hydraulic feed, a 7½ in. dia. x 3½ in. dia. x 10 in. stroke duplex pump being a convenient size. This pump also supplies the hydraulic pressure for the transfer cylinder which moves the machine backwards and forwards over the hole.

At the commencement of a hole it will be necessary to apply pressure on the top side of the piston in order to obtain the correct weight on the bit. When the hole gets deeper the weight of the drill-stem will become greater than the weight that it is necessary to place on the bit; the hydraulic cylinder then holds back the excess weight by means of a water cushion underneath the piston in the hydraulic cylinder. The regulation of the escape of this water from beneath the piston constitutes the feed of the bit.

The routine of drilling with the hydraulic feed when the weight of the drill-stem is greater than the weight allowed on the bit is as follows: Suppose the hydraulic piston to have been fed down to the bottom of its stroke, the weight of the drill-stem is then taken on the swivel by means of the hoisting hook, and the hold of the bottom chuck is released by unscrewing two of the four set screws. The inlet valve at the bottom of the cylinder and the waste valve at the top of the cylinder are opened and the other two valves are closed.

The clear water pump is then started and the piston, and therefore the drive rod and chuck, is raised to the top of its stroke. The inlet valve at the bottom of the cylinder is closed and the chuck tightened up again. The brake is then released and the weight of the drill-stem is thus transferred from the swivel to the hydraulic cylinder.

The water is allowed to escape from the bottom of the cylinder, either through the lower waste valve on the manifold or the pet cock drain; the former is used if a fairly rapid feed is required, and the latter if a slow feed is wanted. It will, therefore, be seen that a very slow yet constant feed can be obtained with the hydraulic feeding device, and that a bit can be fed upwards as well as downwards. This latter feature is useful in certain fishing operations and in reaming out a bit through a tight place in the hole above it.

Handling of the Machine.—The operation of the diamond drill machine does not call for any special powers of strength or stamina on the part of the drilling crew. The control of the brakes is very

light, and the only laborious operations in routine drilling are the tightening up and slacking off of the set screws on the drive chuck, and breaking out the joints of the drill-stem. When using diamond bits the drill-rods are usually broken out by hand with chain tongs or tubing tongs. When using rotary bits the drill-pipe tool joints are broken out with pipe tongs by means of a jerk line worked from the cathead.

Drill-Stem.

When drilling with diamond bits, special flush jointed drill-rods are used. These rods consist of solid drawn steel tubes internally upset at the end, and threaded at each end with a female thread having a modified form of a square thread with a fairly coarse pitch. Into one end of each rod is screwed a coupling which consists of two male ends about 4 in. apart, with a watercourse down the centre, the coupling being screwed tightly into one end of each tube by the manufacturers.

The diamond drill-rods are made in exact lengths of 15 feet, so that it is unnecessary to tape the stands of rods in the derrick. Stands of 60 feet and 75 feet are convenient lengths.

The rods are handled in elevators and, as they are flush-jointed, lifting plugs have to be screwed into each rod so that the elevators can take a hold. These lifting plugs are stacked on a box on the derrick floor and are screwed in and out whilst the elevators are being run up or down. In practice these lifting plugs do not delay the running in or pulling out of the drill-stem (Fig. 6).

Two sizes of drill-rods are used, the larger rod has an outside diameter of $3\frac{1}{2}$ in. and weighs $11\frac{1}{2}$ lbs. a foot; the smaller-sized rod has an outside diameter of $2\frac{7}{8}$ in. and weighs $8\frac{1}{2}$ lbs. a foot. The breaking strength in tension of the large rod is 94 tons. The large-sized rod is now being manufactured in 20-ft. random lengths with a tapered tool joint type of coupling which is made solid with the rod. The new rods are flush jointed on the outside like the old type rod, and are called "Bull Rods."

Foot Clamp.

The drill-rods are held at the derrick floor whilst being run in and out of the hole by means of a safety foot clamp, which is a form of automatic spider operated by the foot. Roughly it consists of a steel frame in which are held two hardened steel jaws. One of the jaws is operated by a foot lever which swings it either in or out; the other jaw is stationary and can be adjusted by means of a large set screw to give the clamp a secure hold on the rods. The rods slide through the clamp when being pulled out,

and are thus protected from any chance of dropping down the hole, as they would be caught by the clamp as soon as they began to drop.

Although admirable for the smaller-sized machines and rods, the writer is of the opinion that the foot clamp should be dispensed with for the large machines and rods, as it is a source of danger and delay when handling the drill-rods, especially when they begin to wear. A spider with slips of the W. K. M. (*i.e.*, segment) type would be much quicker and safer. An automatic spider, such as the Bovaird spider, would be an improvement on the foot clamp.

Core Barrel—Core Shells and Bits.

The core barrel is a special steel tube which is threaded to receive the rods at its upper end and threaded for the core shell at its lower end. Core barrels are of varying lengths and types. The single tube core barrel is the most common, but the double tube barrel has been improved recently, and no doubt will eventually become the standard barrel for oilfield use.

In the single tube core barrel, the circulating fluid, as it passes down to the bit, comes in contact with the core. In soft and friable formations this circulating fluid disintegrates the core and considerably reduces the core recovery, it also tends to "block" the bit, that is, it packs the disintegrated core into the watercourses of the bit, thus shutting off circulation, the bit has then to be pulled out to clear the block. This retards the drilling speed.

With the double tube core barrel the circulating fluid passes down between the two tubes and does not come in contact with the core. The double tube core barrel is therefore much more efficient in coring soft and friable formations and will core rocks which are too soft to be cored with the single tube barrel. The inner tube of the double tube barrel is stationary and does not rotate with the bit; there is therefore no tendency to grind or wear away the core as with the single tube barrel. The single tube core barrel is stronger and not so easily damaged as the double tube barrel, and also much cheaper, hence its popularity. All the figures given in this paper were obtained with single tube core barrels.

The length of a core barrel is about twenty feet, but core barrels having a length of 30 feet and 40 feet have been used on deep holes, where the formations were suitable, to avoid unnecessary pulling out.

An average life for a core barrel can be taken as about 1,000 feet of hole, including total loss and damage in moving.

Core Shell and Core Lifter.

The core shell is a special steel coupling which is placed between the core barrel and the bit, and in the core shell is retained the

core lifter. The function of the core shell and lifter is to grip the core when the bit is pulled off bottom, so that the core is broken off and retained in the core barrel when the bit is pulled out of the hole.

The inside wall of the core shell is tapered so that the inside diameter at the bottom is smaller than the inside diameter at the top. The core lifter is a split ring of tempered steel which is tapered on the outside to correspond with the taper of the core shell; it can therefore contract or expand depending on its position in the core shell. When the bit is run into the hole the core lifter rests at the bottom of the taper in the core shell, the ends of the lifter coming together. As the bit begins to drill and the core barrel works down over the core, the core raises the lifter until it is able to expand in the enlarged upper portion of the core shell, thus permitting the core to pass through the lifter and to enter the core barrel. The lifter is prevented from passing into the core barrel with the core by the shoulder on the bottom of the core barrel.

When the bit is pulled from bottom, the lifter is pulled down into the smaller tapered portion of the core shell which closes the lifter around the core and grips it in a similar manner to a spider and slips.

The core lifter has grooves on the inside which serve as water-courses and also help it to take a better grip on the core.

The temper of the core lifter is a very important matter. If the lifter is too hard it has a tendency to break, the broken pieces are then a great source of danger to the stones in the bit.

Speaking generally the core shell has about half the life of a core barrel and a core lifter has a life of about 300 to 400 feet of hole (Figs. 7, 8 and 9).

Diamond Bit.

The diamond bit consists of a hollow cylinder of soft annealed steel, which screws into the bottom of the core shell.

Flutes are machined on the inner and outer walls of the bit for watercourses. Black diamonds or carbons, as they are called, are set into the face of the bit to serve as the cutting medium.

The bit cuts an annular channel in the formation, into which the core shell and core barrel follow. The centre portion of the annular channel constitutes the core.

The bits vary from 3 in. to 6 in. in diameter and from 3 in. to 5 in. in length; they have four flutes on the inside and four flutes on the outside. The bits are threaded with a male thread, which, like all the joints on the core shell and core barrel, is a modified form of square thread, with a moderately fine pitch.

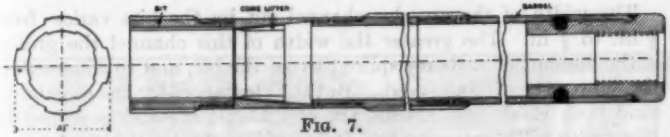

FIG. 7.

SECTION OF SINGLE TUBE CORE BARREL, CORE LIFTER AND BIT.

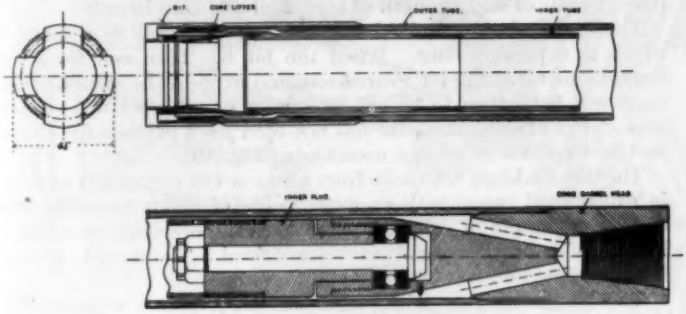

FIG. 8.

SECTION OF DOUBLE TUBE CORE BARREL, CORE LIFTER AND BIT.

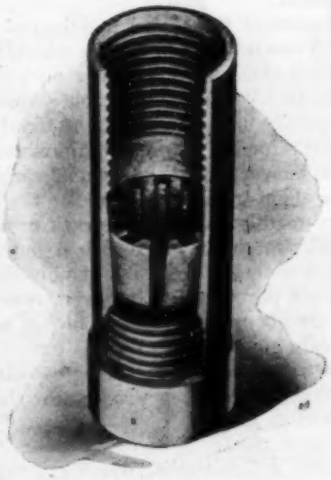

FIG. 9.

VIEW OF BIT, CORE LIFTER AND CORE SHELL.

The width of the annular channel cut by the bits varies from $\frac{1}{4}$ in. to $\frac{3}{4}$ in. The greater the width of this channel the greater is the amount of carbon required to set the bit, and to some extent the slower the drilling speed. But the clearances for the circulating fluid both inside and outside the core barrel are also governed by this width. Therefore in the design of diamond bits the aim is to make the bit with the minimum width compatible with adequate fluid clearances and strength of core shell and core barrel.

The diamonds are caulked into the soft bit blank in a manner which is explained later. When the bit has been run for some time the metal of the bit wears away and exposes the stones. The diamonds have then to be cut out and a new bit set up. If the diameter of the old blank bit has not been worn excessively, it can be faced up in a lathe and used again (Fig. 10).

The life of a blank bit varies from a foot or two to 200 feet or more in exceptional cases, with an average life of about 70 to 80 feet of hole. The life of drill-rods, core barrels, core shells and blank bits depends on the formations being drilled. The wear is greater in sandstones and less in shales and limestones.

The bits are set up with either six, eight or ten stones. The stones being set diametrically opposite to each other. After a good deal of experimenting the writer has come to the conclusion that a bit set up with six stones each having a weight of 4 to 5 carats is the most economical.

With this arrangement two stones cut the outside clearance and two stones cut the inside clearance. The remaining two stones cut the material between the inner and outer stones.

A ten stone bit, that is one with four outer and four inner stones and two stones cutting the intervening material, will cut a shade faster and go a little further before it requires resetting, than a six stone bit, but the increase in the amount of carbon at stake is not justified by these slight gains. The smaller the amount of carbon in a bit the more readily one will sidetrack or abandon a lost bit rather than spend time in trying to fish it out. It must also be remembered that if one stone comes out of a bit when it is on bottom, this single stone will probably destroy every other stone in the bit.

Watercourses are cut on the face of the bit between the stones to permit of a good circulation.

A diamond bit must be handled with great care, it must not be dropped on the floor or the tongs placed near the stones when the bit is being screwed on and off.

Diamonds.

The bit is set up with black diamonds or "carbon" as they are commonly called. The holding of a large stock of expensive

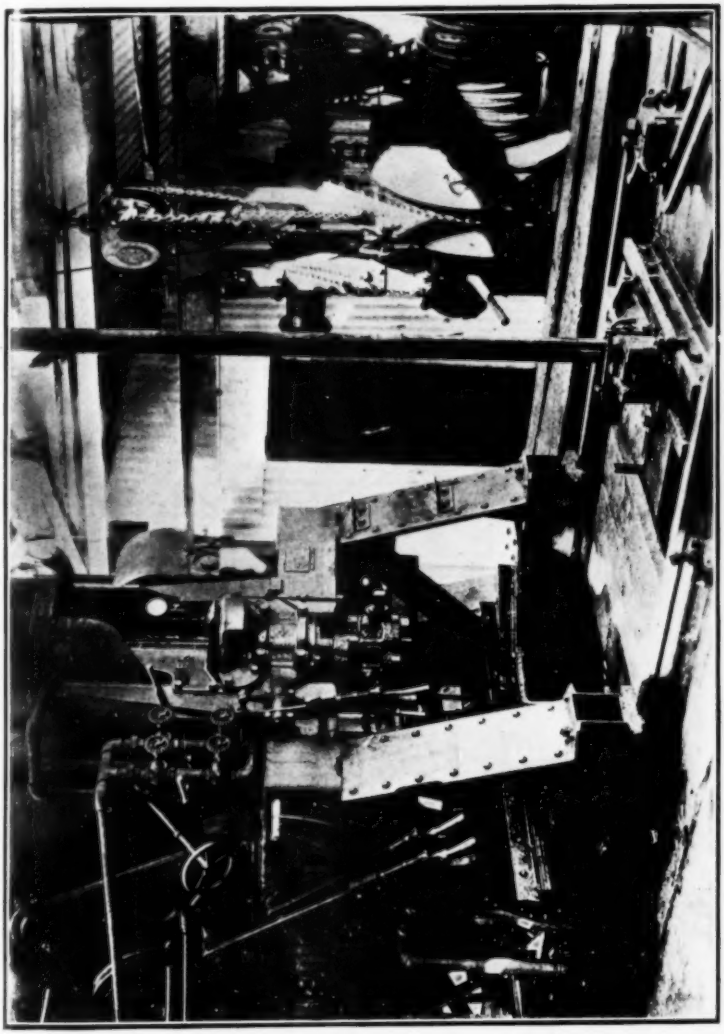

FIG. 6.
VIEW OF DRILL RODS BEING RUN INTO HOLE.

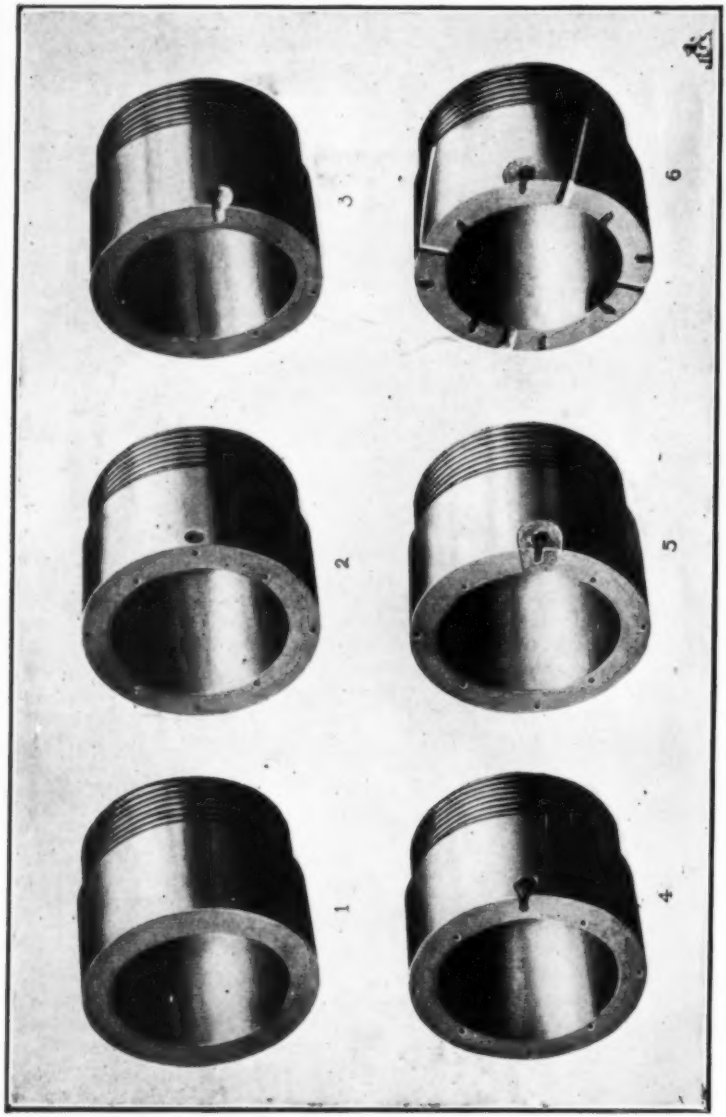

FIG. 10.

VIEW SHOWING METHOD OF SETTING A DIAMOND BIT.

carbon, with the possibility of its loss or damage is one of the disadvantages of the diamond drill. For the continuous operation of the drill a stock of about 80 carats of carbon is required. At present market prices this represents a sum of around £2,000.

Black diamonds are the hardest substance known, they are as hard as white diamonds but less liable to fracture. Black diamonds are almost exclusively mined in Brazil. They have an appearance not unlike that of small pieces of coke and, as mined, average from five to ten carats in weight but are usually broken down into the shape of rough cubes for use in the bits. Occasionally natural stones are used, that is, the stone as found in its natural state and not broken down. These stones are called "naturals." It is usual, however, to chip off the corner of a natural stone so as to expose the texture, otherwise it is difficult to judge the true value of the stone before it is tried out in the hole.

Stones having a weight of from 3 to 6 carats are generally used in the diamond drill bits and small stones varying from $\frac{1}{4}$ to $\frac{3}{4}$ carats in weight are used for reaming down casing and for fishing operations, where their total loss would not be of much import. These small stones are called "casing carbon."

The proper selection of carbon is an important item and it affects the drilling costs appreciably. It has been proved over and over again that the best grade of carbon is the cheapest in the long run. Many substitutes have been tried; most of them are worthless, a few have had a limited success in the softer formations. The only occasion when the use of substitutes is warranted is when the formations are such that there is an unusual danger of damaging the stones in the bit or a danger of losing the entire bit, also in fishing operations, or when pieces of steel have got into the hole. The high price of the best substitutes is such as to greatly discount their advantage over black diamonds even under the foregoing conditions. Sullamite and Stellite are the substitutes most frequently used.

Carbon is judged by four main factors, namely, specific gravity, colour, texture, and shape. Specific gravity and shape are the most important. Good grade carbon for oilfield conditions has a specific gravity ranging from 3·25 to 3·35. Stones with a gravity below this are liable to be soft and those with a higher gravity are possibly brittle, although hard.

It is possible to get a good stone having a gravity between 3.35 and 3.40, but generally speaking the higher the gravity the harder the stone—with a consequent tendency to brittleness. The best stone the writer has ever come across was a natural stone with a specific gravity of 3·30 and weighing 5·02 carats.

FIG. 10.
VIEW SHOWING METHOD OF SETTING A DIAMOND BIT.

Generally speaking the best stones have a steel gray colour on their broken faces without any fleshy tints.

A broken stone should have a fairly close-grained texture, but if the texture is too fine the stone will probably be brittle. a spongy stone is generally soft but it will not fracture so readily as a closer-grained stone. A stone with a slightly spongy texture is the best. Good stones should be free from cracks or shear planes and they should not have any holes or cavities. All stones should be carefully examined under a lens to detect possible flaws.

As very little really hard drilling is encountered under average oilfield conditions, new stones do not get a chance to become rounded up and thereby resemble the correct shape for maximum strength. The best shaped stones are those which approach nearest to the form of a sphere, irregular shaped stones with protruding edges or corners readily break or shatter. If they can be obtained, stones should be bought that have been rounded up in the hard formations of the metal fields. These stones command a premium on the market, but the diamond loss with these stones would be very much less than if new stones were used.

If rounded stones are unobtainable, stones weighing about 5 carats should be bought, so that when the sharp edges and corners have been worn or chipped off, a stone of good shape and weighing about 4 carats will be the result. A stone like this will show little wear under normal drilling conditions.

Diamond-drill manufacturers will select carbons for their customers, some do this service gratis, others charge a small commission.

Setting Diamond Drill Bits.

Diamond drill bits are usually set by the foreman of the drill crew, or if a number of drills are working, a special whole time bit setter will be required. The method of setting is as follows:

The bit blank is securely held in a vice, small bits are held by means of a "setting block"; this is a square or round piece of steel threaded to receive the bit. The setting block is held in the vice and the bit screwed tightly on to the block. The position of the stones is then marked out, the two outer stones will be placed opposite each other and the two inner stones will also be placed opposite each other at 90° to the outer stones. The two clearance stones will be placed opposite each other at 45° to the outer stones. The stones are then selected for the different positions. The outer stones have the most work to do, so the largest and strongest stones are chosen for this position. The outer stones cut on two faces, namely, the bottom or face of the bit and also on the outer wall of the bit, which gives the bit its clearance in the hole. When choosing

an outer stone care must be taken to see that the shape is such that there will be plenty of metal around the stone so that should the bit be pulled into a tight place in the hole, the stone will not be easily dragged from its setting.

The inside stones are next chosen. These stones also cut on two faces, one on the bottom of the bit and the other on the inner wall, to give clearance to the core. As in the case of the outer stones, the stones for the inner position must have two good cutting edges at right angles to each other.

The clearance stones must have a cutting edge sufficient to reach across the space between the inner and outer stones.

When the stones have been selected for the different places in the bit, the setter usually starts to set one of the outer stones. First of all, he examines the stone carefully to find out the best position in which to set the stone in view of the type of formation in which the bit will have to drill. Should the formation be hard, a sharp edge of the stone is set to do the cutting, but if on the other hand the formation is soft, then a blunter edge is set up, or a sharp edge which leans away from the direction of rotation. If a sharp edge is set up pointing towards the direction of rotation the cuttings wear out a hollow in front of the stone which rapidly weakens the setting. He then drills a hole in the bit blank, a little smaller in diameter than the shape of the stone, the hole is enlarged to the size and shape of the stone by means of chisels and punches. If the shape of the stone is irregular, it is not possible to make the shape of the hole conform to the shape of the stone. The spaces around the stone are then filled in with pieces of copper. When the stone is in the correct position, the setter holds it in place with his little finger while he cuts two deep grooves across the face of the bit about $\frac{1}{8}$ in. on either side of the stone with a flat chisel, which he holds between his thumb and first finger. He then cuts a semi-circular groove around the stone, about $\frac{1}{8}$ in. or $\frac{3}{16}$ in. away from the edge of the stone, on the outside of the bit, by means of a round-nosed chisel. The stone is now held in place by the squeezing up of the metal of the bit due to the chisel marks. The setter then begins to draw up the metal around the stone by means of caulking chisels. He starts at the chisel marks and gradually works forward towards the stone.

Care must be taken that the stone is not moved during the caulking operation and that the metal is drawn evenly around the stone so that the pressure on the stone is the same on all sides.

When all the stones have been set, ample waterways are cut across the face of the bit.

The stones are set in the bit so that they protrude about $\frac{1}{64}$ in. to $\frac{1}{32}$ in. beyond the metal of the bit. It is essential that each stone protrudes the same amount, otherwise all the work of the bit will be

thrown on one or two of the stones which project the furthest. The bit is usually set to a ring gauge for outside diameter, so that a new bit will follow the hole drilled by a previous one.

Care and patience are required for setting bits, as an inefficient bit setter can easily damage the stones whilst he is setting them, or else set them so insecurely that they become lost or damaged in the hole.

Casing.

Because of the inability of the diamond drill to bore large diameter holes, and in order to secure the same number of formation shut-offs with the diamond drill as with the other systems, special inserted joint high tensile steel solid drawn casing is used. This special casing is more expensive than the regular screw and collared oil well casing, but it has the advantage of a lower setting depth, less weight per foot, and a longer life. It has the disadvantage of being more susceptible to damage in transit, if roughly handled, than regular oil well casing.

Up to the present time only two sizes of this casing have been used, namely, 5⅓-in. O.D. which is run inside 6¼-in. 28-lb. D.B.X. casing and the 3¾-in. O.D. which is run inside the 5⅓-in. casing.

The dimensions of these two special casing strings are as follows:—

Dimensions.	5⅓ in. casing.	3¾ in. casing.
Outside diameter of body of tube ..	5⅓ in.	3¾ in.
Outside diameter of upset at female end	5⅓ in.	3¾ in.
Inside diameter	(*a*) 4½ in. (heavy) (*b*) 4⅝ in. (light)	3½ in.
Wall thickness	(*a*) ⅜ in. (*b*) ¼ in.	¼ in.
Length of thread	3 in.	2¾ in.
Length of upset	6½ in.	5½ in.
Number of threads per in.	11	11
Taper of threads	1/64 in. per in. on diameter.	1/64 in. per in. on diameter.
Weight per ft. (approximate)	(*a*) 17 lb. (*b*) 14 lb.	10 lb.
Diameter of hole in which casing is run	5¾ in.	4¼ in.
Safe setting depth .. .. .. (Factor of safety = 1·5; sp. gr. of fluid = 1·2)	(*a*) 5725 ft. (*b*) 4370 ft.	6370 ft.

The casing is made from steel having a tensile strength of from 35 to 40 tons per sq. in. with an elongation of 15 per cent. on 8 in.

The joints are supplied in random lengths of from 18 to 22 ft.

The form of the threads is that of the British Standard Specification for pipes.

The joint butts on both the inside and the outside of the tube, the inside of the casing is flush but the outside is upset at the female end in order to strengthen the joint. The length of the upset is sufficiently long to allow of one complete cutting off and re-threading of the female end.

Every joint should be carefully reamed or chamfered on the inside at each end, so that when the joints are screwed together there will be no chance of a projecting ledge formed where the joints butt, due to a slight eccentricity of the joint. A stone in the bit is liable to be damaged should it strike a ledge of this description when the bit is being run into the hole.

As the casing has no collars, special lifting plugs have to be screwed into the joint so as to enable the casing to be handled by elevators; two of these lifting plugs are required so that the casing can be run without interruption.

A diamond bit cuts a clean round hole, therefore casing will follow a diamond drill hole with a smaller clearance between the casing and the walls of the hole without fear of freezing or holding up, than if the hole was drilled with rotary bits.

In the comparatively shallow drilling in Assam, 10-in. 45 lb. D.B.X. casing was used as a conductor and 8¼-in. 36 lb. D.B.X. casing was set at the point below which continuous cores were required. Inside this 6¼-in. 28 lb. D.B.X. casing was set when necessary. These casing sizes were used because the pipe was on hand, salvaged from a previous hole with all the necessary appliances to handle it. It was, however, unnecessarily heavy for the purpose.

The special inserted joint casing has given good service; some of the 5½-in. size has been used on five holes. Originally bought for Algeria, it was shipped to Oran, used there and then shipped back to England. Next it was shipped out to Karachi and used in the Punjab, again it was moved over to Assam and used on three holes there. The writer believes that this must be something of a record for the amount of handling in transport a casing has received—steamer, rail, motor lorry, camel and bullock cart transport being used. The casing never pulled apart, collapsed, or gave trouble of any kind, with the exception of unscrewing in one of the Assam holes when it was being used as a guide string. On one hole it was run in and pulled out of the hole at least six times and stacked in fourbles in the derrick when not in use. A 2,924-foot string was set in Algeria and a 5,311-foot string in the Punjab.

The joints of the casing are usually made up with molten rosin to prevent them unscrewing in the hole. The threads are first heated up with blow lamps and then smeared over with molten rosin before being screwed together (Fig. 11).

Owing to the delay caused by having to use lifting plugs to handle the casing and also the use of rosin, this casing takes longer to run than screw and collared pipe. About 1,200 ft. of the 5½-in. size can be run in an eight-hour tower with native labour.

METHOD EMPLOYED IN DRILLING WITH THE DIAMOND DRILL.

Successful coring is only obtained with bits having an outside diameter of 6-in. and under, therefore if a continuous core is required in the upper portions of a deep hole, the small core hole must be reamed out to enable the larger sized casing strings to be set. This reduces the drilling speed considerably on a deep hole (Fig. 12).

There are two methods of drilling wildcat wells with the diamond drill.

One method is to use the smaller diameter diamond bits and finish the hole with a $2\frac{1}{16}$-in. or $2\frac{13}{16}$-in. bit obtaining a $1\frac{3}{8}$-in. or 2-in. core; this system enables a record of the formation penetrated to be obtained comparatively quickly and cheaply, but if an oil sand were encountered no idea of its commercial possibilities could be obtained with such a small hole.

The other method, which is the one adopted by the Whitehall Petroleum Corporation in India, is to make the initial diameter of the hole large so that should a promising oil sand be encountered, the hole can be reamed out and a proper production test made. The practice in Assam was to set $8\frac{1}{4}$-in. casing down to the point where continuous cores were required, occasional cores being taken with $4\frac{1}{2}$-in. or $5\frac{1}{2}$-in. diamond bits every 150 to 200 ft. above this.

Occasional Cores in Large Hole.—The diamond bit and core barrel are run on the end of the 4-in. drill-pipe. Owing to the large number of pieces of steel at the bottom of the hole, chipped off from the fishtail bits, there is a danger of damaging the stones in the diamond bit unless these pieces of steel are first washed up into a calyx or basket and removed from the hole before the bit is run in.

Fishtail Bits.—The hole for the $8\frac{1}{4}$-in. casing is drilled with fishtail bits and latterly disc bits and rock bits were introduced.

The diamond drill as at present constructed will only drill the softer formations successfully with a fishtail bit, because the machine is not sturdy enough to drill through any hard bands or tough formations. It is essential that a long drill-collar be placed behind the fishtail bit, as this tends to reduce the vibration and flopping of the drill-stem, the jarring effect of which is carried directly back through the machine to the gear box and the engine.

At first only a 4-in. substitute drill-collar was used with the $9\frac{7}{8}$-in. fishtail bits, but later the practice of using a 6-in. by 6-ft. long drill-collar and two joints of 6-in. drill-pipe behind the bit was introduced. This was a great improvement and by acting as a guide also lessened the chances of drilling a crooked hole.

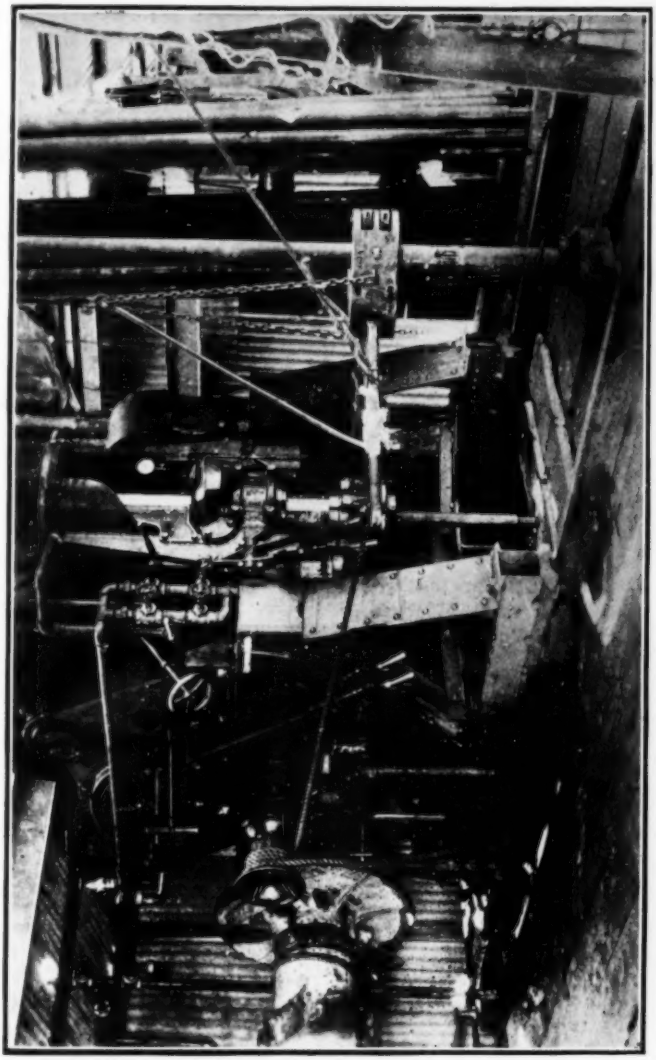

FIG. 11.

VIEW SHOWING JOINT OF SPECIAL FLUSH JOINT CASING BEING MADE UP.

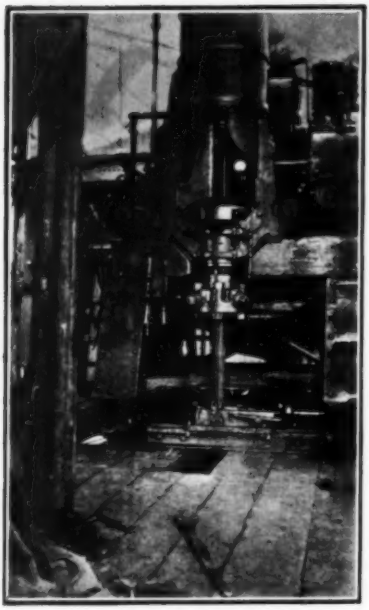

FIG. 12.

THE DIAMOND DRILL IN DRILLING POSITION.

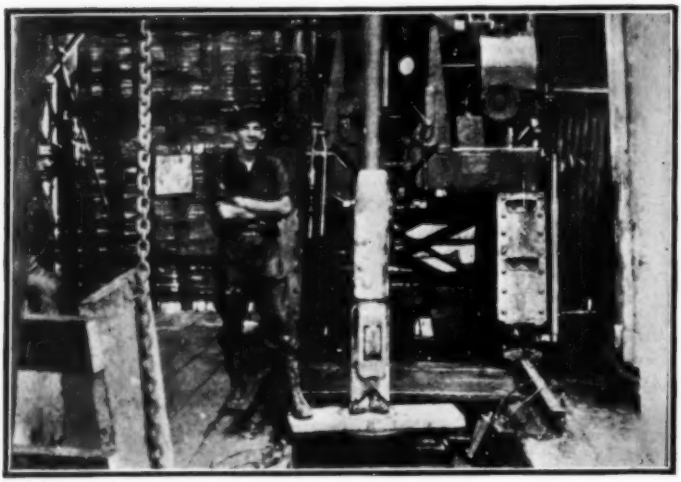

FIG. 13.

DIAMOND DRILL WITH 9¾ INCH HUGHES' ROCK BIT.

Rock Bits.—The Hughes Simplex Rock Bit proved a great success. The diamond drill is admirably suited for drilling with rock bits, and it can get the maximum footage out of a set of cones, due to its sensitive feed. By means of the three speeds obtainable with the rotating mechanism, the correct number of revolutions at which to run the rock bit can be readily obtained; this is particularly helpful when using the self-cleaning cones, as a slow, yet powerful, rotation can be secured. The speed of rotation for a rock bit with self-cleaning cones, for setting 8¼-in. and 6¼-in. casing, is from 25 to 35 r.p.m. The self-cleaning cones were found to be the most suitable for all but the hardest bands, the drilling speed was faster and more footage could be obtained per set of cones than with the regular type (Fig. 13).

The average footage obtained with a set of cones on one hole was :—

Regular type cones	94 ft.
Self-cleaning type cones	144 „
Side reamers	500 „

This was obtained in fairly hard shale, sandy shale and sandstone with a few calcareous bands, and none of the drillers had ever run a rock bit before.

It may be of interest to mention that the Hughes Tool Company use a specially adapted form of a diamond drill machine for carrying out tests and research work on rock bits at their Houston plant, and that the Reed Roller Bit Company have recently installed a similar machine.

Disc Bits.—The disc bit is a tool admirably suited to the diamond drill operating in remote locations, as it does away with the necessity of a tool dresser and the accompanying forge shop equipment.

The cost of drilling with a disc bit is greater than with a fishtail bit, but when the longer time in which the bit can stay on bottom, the wages of a tool dresser or blacksmith, who will only be wanted for a comparatively short time, and the cost of the forge shop equipment are considered, there is a distinct saving in favour of the disc bit.

Another advantage in using only disc bits and rock bits with the diamond drill is that the quantity of steel fragments and chippings, always present in a hole when fishtail bits are used, is considerably lessened, and the large steel fragments which cause so much damage to the diamond bits are entirely eliminated.

The recently introduced "K.P." bit, which somewhat resembles a fishtail bit but has renewable cutters, appears to be an ideal tool for use with the diamond drill. It gets over the trouble of having to dress fishtail bits, and it is not so liable to make a crooked hole as a disc bit.

Casing.—The 8¼-in. casing was set at the following depths in the three holes in Assam; this was the point below which continuous cores were required:—

Hole No. 1	..	..	443 ft., cemented.
„ No. 2	..	..	1000 „ „
„ No. 3	..	..	1035 „ set in oil.

As hole No. 3 was originally intended for a fairly deep test the 8¼-in. casing was set in oil. That is, a column of oil was placed behind the string to prevent it freezing in the hole. The idea was that if it became necessary later on to carry this string deeper, the casing could be pulled and the hole reamed out to permit the string being set at a lower depth. High pressures were not expected, and it was thought that 1,035 feet of 36-lb. pipe anchored to a cemented conductor consisting of 100 feet of 10-in. x 45-lb. pipe was sufficient to take care of any pressure that might be encountered. The shoe had a good seat in shale and a packing clamp was placed between the 8¼-in. and 10-in. casings.

From 40 to 100 feet of 10-in. casing was cemented in as a conductor. It was a disadvantage to use this sized pipe, as it restricted the diameter of the hole for the 8¼-in. casing, but the 10-in. was used because it was on hand, being left over from a previous hole. The conductor was necessary to protect the derrick foundations as the wells were located on a razor backed ridge and on a narrow bench on a steep hillside.

When the 8¼-in. casing has been landed, and the hole thereby made safe should the well come in, a guide string of 5⅛-in. O.D. casing was run inside the 8¼-in. and drilling continued, using a 4⅛-in. diamond bit which takes a 2⅞-in. core.

The guide string was necessary because in diamond drilling the annular space between the outside of the rods and the inside of the casing must not be large, otherwise the cuttings do not wash up satisfactorily and the rods whip about in the casing. The whipping of the rods increases the chance of a twist off and causes the bit to vibrate, which often wears the core to such an extent that the core lifter cannot retain the core in the core barrel.

The guide string is centred inside the 8¼-in. by means of a special shoe, and is supported on the larger casing by a special collar. The two strings of casing are secured together by means of anchor clamps so that should the well come in, the guide string will not be blown out of the hole.

Reaming Out the Hole.—If it is necessary to set a further string of casing the guide string is pulled out and the hole reamed out for 6¼-in. casing with either diamond reaming bits or rotary bits. If the hole is reamed with diamond reamers it must be reamed in two stages, first to 5¼-in. diameter and then to 7⅝-in. When the

6¼-in. casing has been set, the 5¼-in. casing is run in again, as a guide string, and drilling continued with the 4⅛-in. diamond bit. This leaves two more casing strings which can be employed, the 5¼-in. O.D. and the 3¾-in. O.D. casing, finishing up with a 3$\frac{1}{16}$-in. diameter hole.

The Hughes Simplex Rock Bit makes an efficient and quick reamer in all but the very hardest rocks. The self-cleaning cones are better for shales, sandy shales, and soft sandstone, and the standard cones for hard sandstone and limestone. The rock bit must have a long drill-collar behind it, as large in diameter as is practicable, so as to prevent any tendency for the bit to run off.

The great advantage of drilling ahead with a small hole and reaming out afterwards is that a possible oil sand which may be encountered in drilling can be restored to its normal state before making a production test, that is, the coating of mud plastered on the walls of the hole during drilling can be removed by reaming out the hole using clear water or oil for circulation.

Drilling Speed.

Roughly speaking, the speed of the diamond drill is comparable with that of cable tools, or perhaps a little faster on the average; it is much less than that of rotary tools in formations suitable to the latter, As the diamond drill is essentially employed for obtaining information its speed is, within reason, of secondary importance. When the cost of the preliminary geological surveys, the construction of roads, building camps, and moving in material, generally speaking in inaccessible countries far removed from sources of supply, is considered and that the fate of an area which may be a potential oil field all depends on the result of possibly one hole, it behoves one to ensure that the hole yields the maximum amount of information possible regarding the structure being tested. The drilling operations become much more involved than merely punching a hole into the ground.

Another fact which must not be lost sight of is that although the daily drilling speed is possibly much less than that of a rotary hole, the total time spent on a hole may not be very much greater than if the hole had been drilled with rotary tools. This is because the continuous cores obtained enable the geologist to say definitely when the possible oil horizons have been passed and further drilling is useless, whereas with rotary tools the hole must be carried a considerable distance below the point where the geologist *suspects* that the promising formations have been passed, to make sure that this is the case. As an example, two holes in Assam were located on overturned folds. When the steeply inclined bedding planes were

encountered it was only necessary to drill a further hundred feet or so to make sure that the steep dips were persistent, to be able to state with certainty that the axis of the overturn had been passed, and that further drilling was useless. If these two holes had been drilled with a rotary it is highly probable that the holes would have been continued at least 500 feet deeper than they were with the diamond drill, before being abandoned, in order to be certain that the axis had been passed.

The diamond drill operates better in the harder rocks than in the softer ones. Thus faster time can be made in sandstone, limestone, and hard shales, than in softer shales and clays; this is of course when using the diamond bit. As an example on one hole in Algeria better footage was made with a $5\frac{1}{2}$ in. O.D. bit in hard limestone with anhydrite nodules than was obtained in the underlying shales. This is due to the soft shales blocking the bit and cutting off the circulating fluid. The bit has then to be pulled out of the hole to clean out the block.

With the recently improved double tube core barrel the softer formations will be able to be drilled much quicker.

Fishtail Bits.—When using rotary bits with the diamond drill it cannot equal the rotary rig in speed because it has not got the same power and ruggedness. A fishtail bit has to be pulled out to be sharpened more frequently because the machine is not sturdy enough to make hole with anything but a sharp bit. Time is also lost with having to take a fresh hold on the drill stem with the hydraulic feeding device for every two feet of hole drilled.

Rock Bits.—When using rock bits the diamond drill can make as much hole as the rotary and certainly can get more footage out of a set of cores. This is due to the sensitive hydraulic feed which can prevent the bit being crowded down in the hard strata and can feed it down fast through the softer bands. The diamond drill is able to use a rock bit from the surface down, and is not dependent on the amount of drill-pipe in the hole for giving pressure to the bit. The hydraulic feed enables a pressure varying from zero to 20 or 30 tons to be placed on the drill-stem in either direction under perfect control and adjustment. The actual weight on a bit can be calculated to within a few pounds at any time.

Speed Obtained.—The most hole made in India with a diamond bit was 47 feet in a ten hour tower with a $3\frac{1}{16}$ in. bit taking a 2 in. core and using a 40 ft. core barrel. This was at a depth below 5,000 feet.

The most hole made with a rotary bit was 61 ft. in an eight hour tower, using a $9\frac{7}{8}$ in. fishtail bit.

The following drilling speeds were obtained in India with the diamond drill :—

(1) Actual days spent in drilling. All days on which drilling took place are counted, days spent in fishing, reaming, running casing, etc., are not included :—

Location.	Drilled. From Feet	To Feet	Feet drilled.	Drilling days.	Av. footage p. drilling day.
Punjab	4400	6007	1607	65	24.7
Assam No. 1 ..	Surface	1013	1013	35	29.0
Assam No. 2 ..	„	1910	1910	71	26.9
Assam No. 3 ..	„	1914	1914	62	30.9

(2) Actual days spent from starting drilling to the completion of the hole, includes all delays and holidays (no drilling took place on Sundays):—

Location.	Drilled. From Feet.	To Feet.	Feet drilled.	Total days.	Av. footage per day.
Punjab	4400	6007	1607	131	12.25
Assam No. 1 ..	Surface	1013	1013	48	21.1
Assam No. 2 ..	„	1910	1910	244	7.85
Assam No. 3 ..	„	1914	1914	86	22.3

As the three holes in Assam were drilled with the diamond drill using both rotary bits and diamond coring bits, an analysis of the two methods might prove instructive.

Location.	Average footing per drilling day. Rotary bits.	Diamond bits.
Assam No. 1	27 ..	30.4
Assam No. 2	38.5 ..	20.2
Assam No. 3	35.7 ..	26.6

Of course it must be borne in mind that only the upper portions of the hole were drilled with the rotary bits, and they were generally of a much softer nature than those drilled with the diamond bit. In the second hole diamond drilling was resorted to because further progress with the fishtail bits was impossible. If rock bits had not been used in the third hole it would have been impossible to set the 8¼ in. much below 300 ft.

From the foregoing tables it appears remarkable that the figures for the deep test in the Punjab compare so well with those of the holes drilled in Assam, when the depth of the holes are taken into consideration. This is due to the fact that the Punjab formations were favourable to quick drilling with the diamond drill and in general the formations in Assam were not. In the latter case the most frequent rock encountered was a dark grey shale with laminations of grey siltstone, the shale fractured readily on the bedding planes and when these were steeply inclined to the horizontal, which was quite frequently, the core blocked up the core barrel and shut

off the circulation. However, some good cores in this rock were recovered with vertical bedding planes. The severer climatic conditions are also reflected in the figures for Assam.

Reaming.—The speed at which a hole can be reamed out for casing can be taken roughly as twice the speed at which the hole was drilled. Of course, the larger the ledge that has to be cut with a reaming bit, the slower will be the speed, but the above statement can be taken as a general guide.

The following maximum reaming speeds were obtained at the different locations with diamond reaming bits:

Size of pilot hole.	Size of reamed hole.	Location.	Length of tower. Hours.	No. of ft. reamed.
3 7/8 in.	4 1/2 in.	Punjab	10	89
3 7/8 in.	4 1/2 in.	Assam No. 2	8	37
4 1/2 in.	5 1/2 in.	Assam No. 2	8	21
4 1/2 in.	5 1/2 in.	Punjab	10	81
5 1/2 in.*	7 1/2 in.	Assam No. 2	8	17‡
4 1/2 in.†	7 1/2 in.	Assam No. 3	8	27

Running in and out of the hole.—The drill-pipe can be run in and out of a deep hole faster with a rotary rig than with a diamond drill, due to the greater power and more powerful braking of the former, but on a shallow hole the diamond drill is probably as fast as the rotary. In the Punjab, when drilling between 5,000 and 6,000 feet, it took about ten hours to pull the bit out of the hole and put it back on bottom again with the diamond drill. It is only fair, however, to state that in this instance the diamond drill machine was operated at a steam pressure much less than it was designed for. The machine was designed for a steam pressure of 150 lbs./sq. in. and the performance of the machine is calculated on an average pressure of 125 lbs. per sq. in. The boilers that were used were unable to give a steam pressure greater than 110 to 115 lbs./sq. in. at the engine stop valve.

Comparison of drilling speed.—When studying the foregoing figures it must be remembered that they represent the result of drilling operations in India, where climate, inefficient labour, remoteness from supplies; health conditions and many other factors all tend to retard the drilling speed apart from considerations as to whether the formations encountered are good drilling or bad.

The writer has been given particulars of a hole drilled in Tabasco, Mexico, with the Sullivan "F.K." diamond drill, similar to the one described in the paper. This drill spudded in on June 18th, 1925,

* Probably the largest diamond reaming bit ever used.
† Hughes Simplex rock bit with self-cleaning cones.
‡ Using oil for the circulation fluid.

and completed a 4156-foot hole on December 20th following. Ten-inch casing was set at 2115 ft. and the hole was drilled for 8¼ in. casing to 3670 ft., but for some reason the 8¼ in. casing was set at 2790 ft. There was 680 feet of fairly hard lime at the beginning of the hole, and Hughes rock bits were used down to a depth of 1380 ft.

On the deep test put down in the Punjab the hole was drilled to a depth of 4400 ft. with combination rotary and standard tools, the diamond drill was then installed and it completed the hole to a depth of 6007 ft. A comparison of the drilling speeds is interesting.

The combination tools made an average of 20·7 ft. per drilling day (i.e. days on which drilling actually took place) and the diamond drill averaged 24·7 ft. For the portions of the hole on which the rotary alone was used the average footage was 23·05 ft.

Taking the total time into consideration the combination tools averaged 9·6 ft. per day and the diamond drill 12·25 feet (no Sunday work in either cases).

When considering these last figures it is only fair to state that the combination tools had to deal with a high pressure water sand which gave much trouble and that six strings of casing were set, three of which were cementation jobs. To offset this, the diamond drill had the deep drilling to do and had 911 feet of hole to ream out to enable it to set a 5311-foot string of 5½-in. casing. There was also a delay whilst some of the casing damaged in transit was being repaired.

The diamond drill therefore averaged four feet more hole per day than the combination tools and over one and one-half feet more than the rotary tools made on the portions of the hole on which they were used, and this in spite of the fact that the diamond drill was drilling at a depth of from 4400 feet to 6007 feet.

Both outfits were new and the conditions were the same with the exception that the diamond drill had only a white driller on each tower whereas the combination tools had both a white driller and white tool dresser on each tower.

Drilling Costs.

It is difficult at this stage to give actual cost figures for wildcat drilling operations with the diamond drill, as up to the present time only a few holes, scattered all over the world, have been put down by this system.

For the 6007-foot hole drilled in the Punjab, India, previously mentioned, the diamond drill deepened the hole from 4400 feet to 6007 feet at a cost per foot which was 30 per cent. less than the cost per foot of the first 4400 feet of the hole which was drilled with combination tools. In making this comparison, however, it

must be remembered that the combination tools had to deal with an unusually high pressure water sand, and set six strings of casing.

As a matter of interest, the average percentage cost of the various items included in the drilling cost is given for three wildcat holes drilled with the diamond drill in India :—

Item.	Percentage of total cost.
Drilling salaries and labour	20·5
Fuel	14·2
Casing	20·0
Upkeep and repairs	2·5
Carbon loss	6·8
Water service	0·8
Messing	6·8
Field administration	28·4
	100·0

The drilling staff were provided with free board, which is represented by the item under "Messing."

The upkeep of camp buildings and roads, also transportation charges are included under the heading of "Field Administration."

The item under the heading of "Casing" includes all casing run into the hole, no deductions have been made for casing salved at the conclusion of the hole.

No depreciation of tools or equipment has been charged to drilling costs in the above figures.

Personnel.

The labour per tower with white labour is the same for the diamond drill as with rotary tools, *namely*, one driller, or runner as he is called, one derrickman, one fireman, and two floormen.

The rates of pay are more or less the same for the diamond drill crew as for a rotary crew. In tropical countries the native pay roll is less with the diamond drill than with rotary tools, because the equipment is lighter and the work being less laborious can be done by fewer men.

The diamond drill requires a bit setter. The bit setting on a single drill outfit is done by the foreman, who also supervises the operation of the drill in a similar manner to a tool pusher on rotary tools. Where several diamond drills are operating in fairly close proximity, a whole time bit setter will be required in addition to the foreman, leaving the latter free to supervise the work on the various rigs.

If fishtail bits are used to drill the large-diameter portions of the hole, a blacksmith or tool dresser will also be required, but if shop dressed fishtail bits can be obtained, or the hole be drilled entirely with rock bits and disc bits, the blacksmith and also the forge shop equipment can be dispensed with.

Lack of Trained Drillers.

At the present time there is a shortage of highly trained drillers, or runners as they are called in diamond drilling, who are trained to operate the large diamond drill machines and use both diamond and rotary bits. At first rotary drillers were used but they were extremely rough when handling the diamond bits and it has been found that a diamond driller trained on the smaller machine picks up the use of rotary bits and the large diamond bits quicker and more efficiently than does a rotary driller learn the art of drilling with the diamond bit.

The scarcity of fully qualified men for large diamond drills is rather a serious problem as a diamond drill runner can affect the cost and success of a hole to a greater extent than a rotary driller; this is due to the high cost of the diamond bit which he uses, and to the fact that fishing jobs on a diamond drill hole are in general of a lengthier and more serious character than those on a rotary hole.

Geological Supervision.

There is a great saving in geological supervision when the diamond drill is employed, especially for wildcatting in remote places. If a rotary rig is used it is often necessary to have a highly trained and expensive geologist, who will spend his whole time at the location, collecting and analysing the cuttings coming up with the returns, if an accurate log of the well is required.

If a geologist is not kept at the rig it is necessary to have a fairly intelligent and reliable man to catch the samples, wash, bag and label them ready for sending in to the geological office.

With the diamond drill a weekly or fortnightly visit from the geologist is all that is required, as the core is marked for depth at the end of each run and is then carefully racked on trays in a shed for reference.

In fact there is really no need for the geologist to visit the location at all because the core can be shipped to his office complete or representative samples be taken every few feet and be sent to him.

Cores and Core Recovery.

All formations can be drilled with a high percentage of core recovery, except soft shales and clays, and uncemented sands or broken formations. These particular formations can be recovered to a greater extent by the use of double tube core barrels. When it is considered that every year hundreds of feet of complete coal seams are successfully cored all over the world by diamond drills, there is no reason why formations of a similar soft and friable nature cannot be cored in drilling an oil well, if the cores of these soft formations are required.

The new type double tube core barrel has proved to be an efficient tool for coring the softer formations. It has apparently given good results in some recent drilling for potash done by the United States Government in New Mexico. The new type barrel is much stronger and more rugged than the old type double tube core barrels used in mineral prospecting work.

Percentage Core Recovery.—The following table gives the percentage core recovery for the four holes drilled in India :—

Location.	Percentage core recovery.	Formation.
Punjab	86·5 ..	Sandstone and shale, some conglomerate and limestone.
Assam No. 1	72 ..	Sandstone and shale.
Assam No. 2	51 ..	Sandstone and shale, some conglomerate and loose sand.
Assam No. 3	74 ..	Sandstone and shale.

In the case of Assam No. 2, a considerable portion of the hole consisted of a very loosely cemented sand and also shale beds which were steeply inclined and fractured. In the lower portion of this hole the bedding planes were almost vertical. Steeply inclined bedding planes were also encountered in portions of Assam No. 1 and Assam No. 3.

All the above figures were obtained with single tube core barrels.

A high percentage core recovery can be obtained with a single tube core barrel at the expense of the drilling speed by making short runs with the bit of only a few feet.

In certain soft formations the drilling speed can be increased at the expense of the core recovery, this is done by what is termed "grinding core." That is, the core becomes blocked at the bit and instead of pulling out to clean the block the driller keeps on drilling and the core is all ground up at the face of the bit. Some formations grind up very quickly and others hardly at all.

It is claimed by the makers of the new type double tube core barrel that it is impossible to grind core in the softest formation with this tool.

Diameter of cores.—With the diamond bits which were used in India, cores of the following diameters were obtained, namely: 2 in. 2¾ in., and 3¾ in. The majority of the cores were of the first two sizes, the large diameter core being only obtained when taking occasional cores in the 9¾-in. hole.

Generally speaking the larger the core up to a maximum of about 4 in. the greater are the chances of core recovery, but to offset this, it is also true that the larger the core, and therefore, the bit, the slower is the drilling speed and the greater is the tendency for the hole to cave and stick the bit.

The diameter of the 2-in. and 2¼-in. cores is quite sufficient for securing the maximum geological data.

There is a tendency in some quarters to insist on large diameter cores, but the extra expense required to secure these large cores does not seem to be justified.

Diamond Loss.

The actual loss in weight of the diamonds, through wear only, is quite small, and carbon loss is chiefly caused by the breakage of the stones or the complete loss in the hole of a single stone or the whole bit. The diamond loss in the drilling that was done in Algeria and India with the diamond drill has been as follows :—

Locations.	Footage drilled with diamond bits.	Diamond loss in carats per 1000 ft. of hole.	Remarks.
Algeria ..	1150 ..	41·2 ..	Includes one 5½-in. bit containing 28·55 carats completely lost in the hole; 200 ft. of hole was drilled in addition when sidetracking the lost bit
Punjab ..	1609 ..	28·4 ..	Includes one 3 1/16-in. bit containing 18·9 carats completely lost in the hole; 911 ft. of hole was reamed out from 3 1/16 in. to 5½ in. dia.
Assam No. 1 ..	580 ..	7·64 ..	—
Assam No. 2 ..	930 ..	49·8 ..	Heavy diamond loss incurred when reaming over stuck rods and casing with wash over tubes; 360 ft. of hole was reamed out from 4½ in. to 7¾ in.
Assam No. 3 ..	884 ..	1·53 ..	No breakages

The average diamond loss was 25·7 carats for 1,000 ft. of hole, including lost bits, reaming out the hole, fishing, etc. This average covers 5,153 ft. of hole drilled with diamond bits in five locations.

This diamond loss is distinctly high and represents severe wildcat drilling conditions. The high diamond loss is due to the loss of two bits in the hole, and the exceptional loss and damage incurred when fishing at Assam No. 2 and also the bad shape and poor quality of some of the stones that were used.

Reaming out the hole with diamond reamers is often a cause of big carbon loss unless carefully done. This is due to the runner crowding the reamer through an enlarged portion of the pilot hole, the stones only cut a spiral on the walls of the hole as the bit is fed too fast for them to cut a clean hole. When the reamer is

pulled out the stones scrape the walls of the hole and there is a great danger of pulling out a stone from the bit, especially if the bit is worn and the stones have become bare.

Conglomerate, shale containing hard concretionary nodules, or any shattered or broken formation that is at all hard, are liable to cause severe diamond loss. This is because the stones in the bit are cutting alternating hard and soft patches, with a result that a hammering action is produced, which is liable to shatter the stone or tear the stone from its setting. These formations should be drilled with a very light feed and a slow speed of rotation.

In a similar manner steel fragments or any article dropped down the hole are liable to cause damage to the bit. Extreme care has therefore to be taken to prevent anything dropping down the hole and to see that all steel fragments have been removed from a hole previously drilled with a fishtail bit, before the diamond bit is run in.

Drilling into an Oil Sand or High-pressure Zone with the Diamond Drill.

The diamond drill uses flush-jointed drill-pipe or rods, as they are called, and it therefore possesses certain advantages for drilling in purposes, because an efficient oil saver and blow-out preventer can be used. The bit can be fed down against pressure by means of the hydraulic feed.

A check valve is always placed in the rods to relieve the brakes of some of the weight of the drill-stem when running into the hole, and to prevent, as far as is possible, cuttings or cavings from entering the core barrel and rods, and so blocking them.

Owing to the comparatively light weight of the drill-rods it is necessary to snub the lower portion of the drill-stem when coming out of the hole, if the gas pressure is at all high, and to apply pressure on to the rods when running in. This is accomplished by means of a special pulley that fits on the top of the rods, a wire line fastened to one of the derrick sills passes over this pulley, to one of the catheads; thus the rods can be pulled in or let out of the hole at will against oil and gas pressure.

A rod brake, attached to the top of the control head, holds the rods in place whilst a rod is being put on or taken off. The rod brake consists of two jaws which take a powerful hold on the rods by means of a lever and toggle arrangement. The rod brake is compact and is leak tight.

The oil saver is attached to the top of the rod brake.

A diamond bit will drill satisfactorily when oil is being used as the circulating medium. The mud fluid may therefore be

bailed out of the hole when the last water string has been set, and the hole be drilled into the sand using oil for the circulation. This practice prevents possible contamination of the sand with the mud fluid and allows the well to be put on production sooner than if water or mud were used.

Fishing Jobs and Fishing Methods.

Stuck Bit and Rods.—One of the most frequent fishing jobs with the diamond drill is a "stuck" bit, or "stuck" rods. This is caused by cavings or drill cuttings packing around the bit or rods and freezing them in the hole. Sometimes a stuck bit is due to the formations squeezing or slumping in on top of the rods or else the bit is pulled or lowered into a tight place in the hole when the drill stem is being run in or pulled out.

The reason why a stuck bit is a fairly common fishing job on a diamond drill hole is the result of several contributory causes, the first of which is the small clearance between the outside of the drill stem and the walls of the hole, especially at the core barrel and the core shell. The bit, too, is practically the same diameter as the hole, and as it completely fills it, with the exception of the four waterways, it can readily be seen why the bit so easily hangs up.

Another important reason for a stuck bit is the small volume of the circulating fluid. This is especially true when drilling soft shales and clays with a single tube core barrel. In order to obtain the maximum core recovery and footage, the runner will drill these formations with the minimum amount of circulation, so that the core is not disintegrated and washed away in the core barrel. If the runner does not reduce the volume of the circulation there is every possibility of the core in the core barrel being washed and broken up, and this will reduce the amount of core recovered and also "block" the bit, thus necessitating pulling out the rods to clear the block.

When using the recently improved double tube core barrel it will be possible to drill with a much larger volume of circulation without fear of spoiling the core, and the chances of a stuck bit when using this barrel will therefore be less than when a single tube barrel is being used.

If the volume of the circulation is inadequate, the cuttings do not wash up properly. The heavy cuttings will only wash up a short distance above the bit and will then remain more or less stationary, probably at some enlarged portion of the hole where the velocity of the circulating stream is diminished due to the increased area. When the circulation is shut off preparatory to pulling out the bit or even whilst adding on an additional rod to the drill stem, the

heavy cuttings will settle back down the hole. If they are there in quantity and are given sufficient time to settle back they may pack around the rods or the bit and stick them.

Leaking rods may be the cause of sticking a bit in this manner, for although the circulation stream coming from the outflow pipe into the ditch may appear quite adequate to bring up all the cuttings, yet only a fraction of this fluid may be passing through the bit if the rods are leaking badly.

Loss of circulating fluid to the hole is an additional cause of stuck bits and rods. In this case the bit drills into a cavity or creviced formation, which allows the circulating fluid to escape from the hole. The lowering of the fluid level due to this loss of fluid may cause unconsolidated formations to cave in and stick the rods. Where the formations are consolidated and not liable to cave, the loss of circulating fluid, which under these circumstances may be water, does not matter very much. Hundreds of feet of hole have been drilled with the diamond drill when not a drop of the circulating water has been coming back into the returns ditch.

Methods of Recovering a Stuck Bit.—Generally speaking the fishing operations are similar to those employed on rotary tools when the bit or pipe hangs up in the hole. Oil is often circulated to try and free the rods. The rods are also relatively slender and will not stand much jarring.

A spear or left-hand tap is used for backing off the rods. The spear is simply a square-tapered shank that fits into the drill rods and takes a friction hold, enabling them to be rotated in either direction. The hold on the rods can be broken by taking a strong pull on the spear. The spear is heat treated on its tapered portion.

When using the smaller sized bits the space between the wall of the hole and the rods is quite small. Washover tubes, if they can be used at all, have to be made so thin that they are very light and frail and have to be handled with great care.

In anticipation of a stuck bit the runner usually tries to keep the joint between the core barrel and the bottom rod well wicked and lubricated, so that, in the event of a stuck bit, the rods may be backed off to the top of the core barrel at the first attempt, thus saving a lot of time and trouble in backing off.

Burnt Bit.—A burnt bit occurs when the bit is allowed to drill on bottom without circulation. The bit gets hot as it cuts the rock, when there is no circulating fluid passing through to cool it. It becomes red hot and eventually melts, fusing some of the surrounding rock at the same time.

The diamonds are melted from their setting, and when the bit is finally recovered they may be found anywhere in the fused mass of metal and rock. A stone that has been burnt in a bit often becomes

brittle, and soon breaks up and shatters to pieces. There is also a danger of losing one or more of the stones from the bit when it is badly burnt.

Usually the bit tends to close up, after the manner of a bull plug, when it begins to burn.

Leaking or split drill-rods are the chief causes of a burnt bit. The returns coming into the circulation ditch and the action of the slush pump may appear to be in order, when perhaps not any of the fluid is really going through the bit, for it may all be coming from leaking rod joints or a split in one of the rods.

A diamond driller should use special care when he knows his rods are in poor condition, but in any case a burnt bit is a result of carelessness or inexperience on the part of the drill runner, as the action of the drill stem will tell him that his bit is not getting adequate circulation, long before the bit burns itself in so fast as to make it difficult to pull out.

Methods of recovering a burnt bit.—If the bit has only just started to burn when it is discovered, it may be possible to rotate the rods a little or move them up or down a few inches but not possible to pull the bit out of the hole. This is due to the bit, core and surrounding rock fusing into a lump which will not pass through the hole. The burnt bit must then be rotated and worked up and down until it is worn sufficiently to allow it to pass through the hole. If the bit can be pulled up and rotated opposite a layer of sharp grained sandstone it will soon be worn down sufficiently to come freely out of the hole.

Should the burnt bit be fast and be impossible to move, then it will have to be recovered in a similar manner to that previously described for a stuck bit. Quite often a badly burnt bit will cause a " twist off " at the core barrel or core shell so that the slow proceeding of backing off the rods is not always necessary.

Twisting off the Drill Stem.—Twist offs are not common unless worn or crystallized rods and fittings are being used, or if small diameter rods are used in a large hole.

A twist off usually occurs at the threaded portion of the joint between the bit and the core shell, or between the core shell and the core barrel. Sometimes a core barrel head twists out, but this is unusual. When the rods fail they usually break off at the base of the male portion of the drill rod coupling thread.

Methods of Recovering Twisted off Rods, etc.

The twisted off rods are usually recovered by means of a fishing tap. As the rods are flush-jointed, overshots cannot be used.

The sensitive control on a diamond drill takes a lot of the uncertainty out of fishing jobs. The fishing tap can be backed down very lightly on to the fish, so that the action of the tap entering the lost rods can be felt. The tap is made up by hand with chain tongs, the number of turns being noted.

Fishing for Core.—This is probably the most common fishing operation on a diamond drill, and yet it is not, strictly speaking, a fishing operation in the usually accepted meaning of the phrase.

When drilling some formations, particularly certain types of sandstones, the core wears small and the core lifter fails to hold the core. Or it may be that a sharp grained sandstone has worn the core lifter to such an extent that it is too large to grip the core. Under these circumstances the core is left at the bottom of the hole, or sometimes the core may drop out of the core barrel as the rods are being pulled, wedging in the hole as it drops down, thus forming a bridge.

If the bit is pulled out and no core has been obtained, when the action of the drill has indicated that the bit was coring (sometimes core can be all ground away as fast as it is drilled) then efforts must be made to fish out the lost core. This is done by running into the hole with an old worn blank bit with a new core lifter, or a core lifter that is a fraction smaller than the regular lifter, so that it will retain the worn down core.

Should a diamond bit be run into the hole when core has been lost there is every possibility of damaging one or more of the diamonds as the bit is being run over the old core. It is for this reason that a blank bit is used, and an old worn bit slips over the core more easily than a new one. Apart from the danger of breaking one of the stones, and also the danger of breaking the core lifter if it is tempered on the hard side, a full run cannot be obtained with the bit if the hole contains lost core.

To avoid the possibility of breaking the core lifter when fishing for core, the lifter is usually put on a fire and the temper drawn until it is quite soft. Pieces of broken core lifter in a hole are a menace to the diamonds, as they cause them to break and shatter.

Sometimes two core shells and lifters are run with the "core picker," as the old blank bit used for fishing core is called. The two core shells are connected together with a special substitute.

Fishing for Lost Diamonds.—Sometimes one or more of the diamonds set in the bit will pull out from their setting and become detached in the hole.

In some cases this can be caused by the bit being run too long before it is reset. The metal of the bit wears away and therefore

the protecting metal which holds the stone in place is diminished until the setting becomes so weak that it cannot retain the stone. A badly set stone will also become quickly detached from a bit.

Even if a properly set bit is pulled up into a tight place in the hole there is a possibility of pulling out one of the outside stones.

In order to prevent the bit from becoming badly worn, with the consequent danger of losing one or more of the stones, a diamond bit is often pulled out to "look at the bit" long before the core barrel is full. This is particularly true when drilling sharp sandstones which wear the metal of the bit away very rapidly.

When a stone is pulled out from its setting there is always a fear that it may damage the other stones, should it get underneath the bit. The lost stone may also cut the core barrel or rods in two should it become lodged up in the hole where the formation is hard.

Method of Recovering Lost Diamonds.—If the formation being drilled is fairly solid there is a good chance of recovering a lost stone.

The usual method is to run a diamond point bit and make the bottom of the hole like an inverted cone, so that the lost stone will rest in the hollow in the centre of the hole. A steel bit or a bit set up with scrap carbon is then run in and a foot or so of hole is made. The lost stone will then be brought up on the top of the core.

Another method is to drill a hole in a blank bit a little larger than the lost stone and fill it with tar or similar substance. The bit is then run into the hole and run lightly on bottom. The circulating fluid drives the stone to the outside of the hole underneath the bit and when the stone comes underneath the hole in the bit it drops in, and is held there by the tar whilst the rods are being pulled.

In one instance that came before the writer's notice a stone was pulled out of a bit and all efforts to recover it having failed, the hole was continued with the same bit which was then minus the missing stone. On pulling out the bit a day or two later the runner was amazed to find the lost stone back in its setting! The stone had evidently been lodged in a crevice and had then fallen back into the hole. Getting under the bit and having nowhere else to go it had been pushed back into its own place in the bit.

Sometimes a lost stone can be washed up. An old blank bit is run down to bottom and a good circulation maintained for several hours. A screen is placed under the outflow pipe to catch the stone should it be washed up.

A stone may be washed up by reversing the circulation, that is, the fluid is pumped down the outside of the rods and returns up

the inside. This is a dangerous proceeding, however, in any but the most solid formations as there is a danger of the walls of the hole slumping in and sticking the bit.

Another effective method of recovering a lost stone is to run a calyx tube, the pump is started and stopped several times so that the lost stone will be washed up the hole for a short distance and then drop back when the pump is shut down. The stone falls into the calyx tube as it drops back and is recovered when the tube is pulled out. This is also a good method of removing small pieces of steel from a hole.

Spinning Off.—Sometimes the bit, core barrel, or rods will unscrew in the hole whilst the drill-stem is being rotated. This is called "spinning-off." Usually it is the lower portion of the drill-stem that spins off.

Spinning off occurs more frequently in the angle holes drilled in the metal mining industry than it does in the vertical holes drilled for oil. It is due to the flywheel effect of the rotating rods and bit when the rotation of the upper portion of the drill-stem is checked, either by friction in the hole or by the driller suddenly stopping the rotation of the machine. The lower portion of the drill-stem has a tendency to rotate after the upper portion has come to rest, thus unscrewing the rods. Of course, the tendency to unscrew is greater if the rods are rotating off bottom.

The power of rotation necessary to drill with a diamond bit is quite small, as a result, therefore, the rod joints never get set up tight as they do when using rotary bits.

One of the precautions taken to prevent spinning off is to make up the drill-rod joints quite tight with chain tongs when the rods are run into the hole. Another precaution is to never shut off the engine suddenly when it is necessary to stop rotating. The steam should be shut off gradually so that the rods come slowly to rest.

When the rods have been spun off the fishing operations are the same as for a twist off, with the exception that if the unscrewing of the drill-stem has been noted immediately it took place, so that the threads are not damaged by being run on, the rods can often be screwed together again in the hole without any trouble. Of course, if the hole is enlarged or small rods are being used in a large hole, it may not be possible to engage the lost rods without running a bowl.

Measuring the Deflection of Diamond Drill Holes.

Owing to the comparatively small clearance between the bore of the hole and the outside diameter of the flush-jointed drill-rods,

the taking of deflections in diamond drill holes is comparatively simple. The method employed is as follows:—

A watertight steel tube that fits snugly into the bore of the drill-rod is screwed into the watercourse of the drill-rod coupling and thus held securely inside the rod. Inside this steel tube is a glass tube, half full of a weak solution of hydro-fluoric acid. The glass tube fits snugly into the steel tube and the acid is retained in the glass tube by means of rubber plugs.

Several of these tubes will be placed in the rods at points where it is desired to obtain the deflection, and the rods will then be left in the hole for a period of from one to three hours, depending on the strength of the acid solution. The depth of each test tube is carefully noted.

The acid solution will etch a ring on the inside of the glass tube at the surface of the fluid. The complement of the angle which this ring makes to the axis of the tube is the deflection of the hole. The weaker the acid solution the clearer and more accurate will be the line etched on the glass tube. If the acid is too strong the line will be blurred, or a line will be marked on the glass whilst the rods are being run into the hole, making it impossible to get a correct reading for the test.

As the hole cannot be circulated whilst the deflection test is being taken, it is not advisable to run the rods below the bottom of the casing unless there is no danger of the formation caving in on the rods.

This method of measuring the deflections of holes is probably accurate to plus or minus one degree if carefully done; it is the system employed for checking the deflection of angle holes in mineral prospecting work.

If a theodolite is set up some little distance from the derrick and a sight taken at the top and bottom of each stand of rods, to make sure that they do not turn as they are pulled out, and the tubes marked before they are withdrawn, then the direction in which the hole is deflecting can be obtained.

The deflection of a 3700-ft. hole in Algeria, drilled by standard tools to 2600 ft. and then deepened by the diamond drill, was found to be 2 deg. at the bottom of the hole. The deflection of the 6007-ft. hole in the Punjab was 1 deg. at a depth of 5311 ft. The deflection of the Assam No. 2 hole was found to be 12 deg. at 1000 ft.; this was drilled by the diamond drill with fishtail bits. Below 1000 ft. the drilling was done with diamond bits and the hole had straightened up to a deflection of 10 deg. at a depth of 1600 ft.

Conclusion.

It will be seen that in the diamond drill we have yet another drilling system available for the benefit of the oil industry. The diamond drill will never compete with rotary or standard tools for ordinary routine production drilling, except in a very few instances where the formations and conditions are suitable for the diamond drill. But for structure drilling, for drilling test wells on new or untested structures, for proving up the limits of an existing field, for finding out the existence of deeper sands in a productive area and for any other instance where a certain amount of speed in drilling may be sacrificed for the greater abundance of geological data obtained, the diamond drill is by far the most suitable drilling method at present on the market.

As mentioned at the beginning of this paper, there is also another field of usefulness for the diamond drill, and that is the deepening of existing holes whose diameters have been reduced to such an extent that standard or rotary tools are unable to carry them any deeper. Up to the present time the diamond drill has been chiefly engaged on this class of work in the oil industry, apart from the structure testing carried out by the smaller machines, although it is now being increasingly used to drill holes from the surface down. The diamond drill is also used for drilling in high-pressure formations where its flush-jointed rods and hydraulic feed are a big advantage.

The diamond-drill machine as described in this paper has been used in the following fields:—

Assam and Punjab, India; Signal Hill, California; Tonkawa, Oklahoma; Powder River, Wyoming; Calgary, Canada; Tabasco, Mexico; Baku, Russia; and Peru.

It can definitely be said that the diamond drill has passed out of the experimental stage in the oil industry and, with the periodical improvements which will, no doubt, be incorporated in the machine and system from time to time as a result of co-operation between manufacturers and producers, the diamond drill is destined to become a strong armament on the side of the oil operator in his perpetual war with nature.

The writer is indebted to the Whitehall Petroleum Corporation for permission to publish the information relating to their operations.

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DISCUSSION.

The Chairman, in opening the discussion, said the members by their applause had expressed their thanks to the author for the very valuable contribution he had made to the Institution.

Their thanks were also due to Mr. Chambers for so kindly undertaking the very onerous duty of reading the paper.

To his mind the paper brought out one very striking point, namely, the advance which was being made in what he might term the science of drilling since the paper was written. The members would have noted that the last sentence of the paper stated that it was originally written in December, 1927. Since that time many advances had been made, particularly in rotary drilling, and by the use of hard cutting agents in connection with core bits. The paper dealt with a very hard cutting agent, the diamond, but the other means which had been adopted had certainly given very excellent results. The author referred to two systems only; the paper was primarily on diamond drilling, but mention was made of rotary drilling. In addition to diamond drilling there was the chilled shot method which was much more economical in operation because the cost of chilled shot was only £15 per ton, and it might be taken as an average that a ton of chilled shot would drill a thousand feet of hole. In comparison with the figures given by the author that represented a very considerable saving. The diamond drill was reputed to cut a very clean core, and undoubtedly it did. Some of the specimen cores exhibited at the meeting were extremely good, but he had brought with him that evening a core which was obtained with chilled shot which, to his mind, was just as clean as any of the other cores exhibited.

On no less than three occasions in the paper the author referred to the use of lifting plugs for handling flush-jointed rods.

Fig. 14 illustrates a slip ring elevator, which was particularly suitable for dealing with any type of casing. The grip does not take place underneath the collar, but around the casing, and as the grip from the slips is circumferential, no damage is done.

He desired to challenge one statement made by the author regarding the speed of diamond drilling compared with cable tools. Ten years or more ago it was a regular practice in the Oklahoma fields of America to finish a well 3,000 ft. in depth, completely drilled and cased in one month, by cable tools, and he ventured to submit that those figures were very much in front of any that had been submitted in the paper that evening. The author made the statement that the diamond bit, as used in the Assam wells, was run in tours of 10 hours, and the rotary in 8-hour tours. Taking the relative figures, and putting the rotary on the same basis as the tour with the diamond bit, it would be found that the rotary showed a much higher speed.

Mr. B. J. Ellis said it was very curious that whenever the subject of diamond drills was mentioned to him the one point

that was always made in favour of the diamond drill was that it could drill with every other imaginable type of drilling bit. It was not particularly suitable for use with bits other than the diamond core crown, and its use with other bits was more or less in the way of a makeshift. It was stated that diamond core bits were not very satisfactory above 6 or 8 ins. in diameter, so that the diamond drill, as such, was not very suitable for use in oil well drilling. It had, he thought, a use for deepening oil wells when they had got down to extraordinary small sizes of casing. The ordinary rotary outfit with a table 4 ft. or so diameter and weighing up to 4 tons could not easily handle $2\frac{1}{2}$ in. drill pipe at a depth of 6,000 ft. On the other hand, the diamond drill was a much more delicate machine, and he felt sure that it would find a place for itself in the drilling of very small diameter holes. So far it did not seem to have made much progress, but he thought there was every chance that it would do so in the future. He thought those who were responsible for the manufacture and sale of diamond drills made a mistake in trying to advocate them for the drilling of oil wells from the surface. Diamond drills were essentially machines for small holes, and he thought they should be kept to that purpose. One feature to which the author did not refer very fully was the ability of the diamond drilling machine and its equipment to drill under pressure. That was a very valuable asset, and systems embodying that feature were coming more and more into use every day. Two new drilling outfits had been developed within the last three or four years in the United States, and they were both going ahead slowly but surely, simply because they were able to drill under pressure. The control of wells became more and more difficult as the wells got deeper and the pressures became greater, and the expense of controlling wells by means of heavy mud had mounted up and up until some means of controlling them, other than those in use before flush-jointed drill-piping was used, had become absolutely necessary. He was sure that in the near future a very great increase would be seen in the use of flush-jointed drill-pipes as a means for controlling wells. He thought it would be of interest if the author would state why such a very small hole was drilled in the first place in Assam, and later reamed out. He noticed that the hole was actually $3\frac{7}{8}$ in. in diameter and was later reamed out to take a 5-in. casing. If a diamond drill could drill satisfactorily with a 6-in. core, why was not the hole drilled straight away with the larger 6-in. bit? One point in the paper which particularly interested him was the reference to the inclinometer, and the method mentioned of keeping the rods from turning when they were being brought out of a hole by using a theodolite. That he

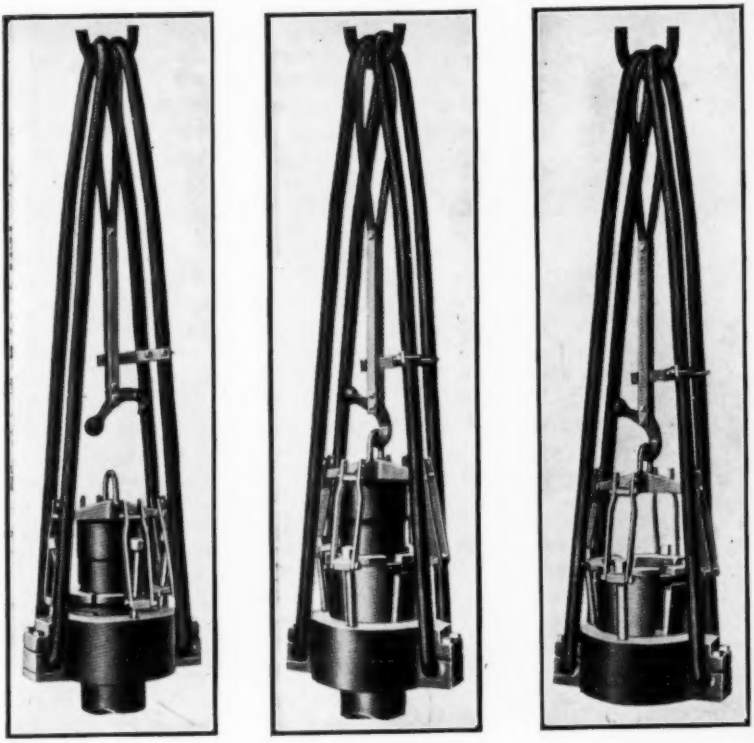

FIG. 14.

SLIP RING CASING ELEVATORS.

Elevator with Slips in position to pull casing.

Slip Hook engaged, Elevator Bowl backed down releasing Slips and Elevator is in position to be taken off from the casing.

Complete Elevator. Slip Hook engaged. Slips raised, ready to place Elevator over or to take off casing.

believed was the system used by practically all the American well surveyors, who stated that they could give the direction and the deviation of a hole. It must be borne in mind, however, that the proportion of a string of 6,000 ft. of 2½-in. drill-pipe was about the same as a thread 1/1000 in. in diameter and 2 ft. long. When it could be proved to him that a thread 2 ft. long and 1/1000 in. in diameter would not twist when moved then he would believe the statement that inclinometers run in the way suggested could tell in which direction the hole had gone. Personally he thought it was impossible to tell exactly in which direction a hole deviated by any means so far in use.

Prof. V. C. Illing said that his own association with diamond drilling was essentially from the geological point of view, and any remarks he made would deal largely with it from that point of view. He thought all the members would agree with Mr. Ellis that one of the great possibilities of the use of the diamond drill was for deepening holes which were already so small that by no other method could the hole be drilled deeper and thus obtain full information of the strata below. The chairman had referred specifically to the question of chilled shot cores. On the whole he did not think there was very much to choose between the quality of the core which was obtained by one system or another. He had had the pleasure of examining most of the diamond cores from the well in Assam, and recently he had been examining chilled shot cores from South Africa, and certainly both systems gave very excellent geological information. He desired to emphasise one point with regard to diamond drilling as it appealed to geologists. They were perfectly certain with that system that what they were getting was a true sample of the material *in situ*, with the minimum of interference with its original structure. It was quite true that with the rotary system a core could be taken, and that in regard to the particular place from which it was obtained information could be obtained. If the places were carefully chosen a good idea of the structure downwards could be obtained in that way. But naturally the rotary coring was not continuous, while diamond coring or chilled shot coring gave a much more complete record of the strata being passed through. Unfortunately, when geologists were testing for structural evidence they did not always know where they would get the information desired, and therein, he thought, the diamond drill played an important part in the drilling of wild cat wells. An instance of that was the wells drilled in Assam. The first well drilled there was on the core of an anticline, and it was very important to decide exactly where the crest was. The decision rested largely on the question of what the rocks

were going to do, and those who were concerned with the problem considered that they would probably get a case of fairly flat dips; then, as it was known the crest was sharp, secondary folding in the soft formation, and then probably verticality. The geologists would probably have obtained a fair estimate of the nature of the ground that was being passed through by the use of another system, but in the diamond core, before the crest was crossed, the secondary folding in the clays was clearly displayed. With regard to the cost, knowing as he did something of the formations that were being drilled both in Assam and the Punjab, he thought it was hardly fair to compare the drilling speeds and costs in those areas with ordinary normal rotary practice in oil fields where the formations were usually much softer. The softest of formations were not being dealt with, and personally he would like to know what a diamond drill would do in the soft putty-like beds that were sometimes met with in oil practice. Perhaps the conditions of pressure would enable it to compete, but he thought probably the relative value of the two systems would not be so favourable to the diamond drill in these conditions. One other point he wished the author had dealt with more fully related to the obliquity of the hole. He did not know whether any of the members possessed any information on that point, but he would like to know what was the relative deflection of the rotary and the diamond systems. In drilling a well cores were obtained showing the structure, and it was possible to get angles of dip with relationship to the hole. Uncertainty existed as to the direction of deflection of the hole, and they did not know whether to add or subtract this factor. It would certainly be a great help if someone would give an authoritative account of the surveying of boreholes. Finally, he desired to congratulate the author on a very readable account of the diamond drilling system; it was certainly a good thing to have in the Institution's publications a clear and concise account of the diamond system, whether it was applicable to normal oil drilling or not. It was undoubtedly applicable in certain problems in oil-field exploration.

Dr. J. A. L. Henderson said that comment was called for in regard to certain of the statements in the paper. For instance, the very important question of deflection of diamond-drill holes was cursorily dealt with, and dealing with the surveying of crooked holes, the author mentioned only two methods which are not only inefficient, but may be seriously misleading, not only in regard to the direction of the borehole but also the inferred attitude of the strata traversed. It was to be regretted that the author had not given more time to a description of modern methods of

surveying such boreholes—a subject to which Prof. Illing had referred—in view of the invariable tendency to serious deviation from the vertical, with a resultant sinuosity of ultimate course as great depth is attained. That was one phase of the subject, when drilling for oil, which he thought should be carefully studied. Speaking from the experience of the practice with which he was familiar, he did not see how it was possible for any borehole to remain vertical after a thousand feet or so, and when using the diamond drill in highly inclined beds, totally wrong conclusions had been formed prior to checking the results by accurate survey. The deep boreholes in the Turner Valley area, near Calgary, drilled by standard or by rotary tools, which were being deepened by means of diamond drills would, he hoped, afford a great deal of enlightment on that subject, because the work was really structural drilling in highly inclined beds at great depth. As the work was being undertaken under the supervision of experts on the subject, he hoped the Institution would be able to secure a paper dealing with that particular phase of diamond drilling, which would be of great value to all associated with drilling for oil. With regard to the question of the comparative speeds of drilling, he thought the author's figures could only be taken as applicable to the particular conditions which he was describing. It was well known that standard tools could drill very much more quickly than diamond drills under other conditions, and the Chairman had given an instance of that in the remarks he had made.

Mr. S. H. Chapman said he would like to know whether the small size drill-rods were thoroughly satisfactory, especially in very deep borings, and if "twists off" were not very frequent. He would also like to know whether any of the new alloys that had been tried could really take the place of the diamond. The Chairman had mentioned chilled shot as being cheaper than diamond. Chilled shot might be all right where clear water was used, but surely where it was necessary to use circulating mud the chilled shot would float out in the mud and, therefore, could not be used.

Another question he wished to ask was whether it was safe to drill with the diamond crown in soft or alternating soft and hard formations. The formations encountered in the Punjab from 4,000 ft. to 6,000 ft. were, from the cores, evidently very hard. Suitable rock bits and modern double core barrels could be used with ordinary rotary and, in deep holes of small diameter provided there was a gauge in the derrick attached to the fixed end of the draw line for checking the weight of the tools, and not too heavy a rotary and engine, there did not seem to be very much advantage in using a machine which was designed primarily for the use of

the diamond crown. As pointed out by the author, hydraulic feed was, of course, extremely advantageous, but again, there was nothing against hydraulic feed being used in conjunction with the ordinary rotary table.

Mr. C. E. Capito said he had not had any experience of diamond drilling, but he agreed with Mr. Ellis with regard to what might be called the misuse of rotary tools on a diamond machine. In his opinion the principal advantage of a diamond machine was its portability and economy both from the point of view of the total tonnage which had to be shipped to a test area, cheaper casing and saving in the cost of making roads. Sites for oil wells are often miles from anywhere, and in very difficult country the saving in the cost of road making is most desirable, and can best be done by bringing down individual maximum weights. For example, it is possible to carry a length of 10-in. casing weighing about 850 lb. between four mules on mountain tracks about 6 to 10 ft. wide with grades of 1 in 4 or even steeper, and if individual weights of machinery and casing can be reduced to or below this figure a road for vehicular traffic need not be made. If there were just one or two pieces weighing more than 850 lb. it is possible that these could be manhandled on to the site. He desired to ask Mr. Chambers if he could give the weight of the largest individual pieces of the diamond drilling machine when dismantled as far as possible. No mention was made in the paper of the fluid which was used for lubricating the diamond. Was it of the same specific gravity as that used in a rotary; or was oil or plain water used? Reference had been made to the question of measuring the deflection of the hole. He agreed with the remarks Mr. Ellis had made about the theodolite. Personally he had had experience in one hole of 9-in. casing shifting about 15 ft. at the bottom of the hole. The casing was broken in pulling it out and had to be recovered in sections by unscrewing, but finally he brought up the last 300 ft. It was found to be permanently badly bent or curved, but this was 9-in. casing; a 2-in. pipe could be bent to a greater amount and would probably spring back and not stay deflected, and therefore not show the true deflection of the hole. The method mentioned in the paper of using a glass tube half-full of a weak solution of hydrofluoric acid for the taking of deflections seemed to him to be very lengthy when run in on the drill-pipe. It was mentioned that it took ten hours to get in and out of a 6000-ft. hole. If hydrofluoric acid was shaken about in the glass tube for 5 hours while running in it was not much use leaving it stationary for another 3 hours and then shaking it about for another 5 hours when

pulling out; there would appear to be little left of the etching on the sides of the glass tube to show the true deflection of the hole.

Where a power winch was not available he suggested that a fourble of drill-pipe with the glass tube and hydrofluoric acid in the centre of the stand be run into the hole on a light sand-line by means of a hand winch. It could be pulled out by the same method or else by the use of horses or mules, whichever were available. This method would give much quicker and, to his mind, more accurate information than that suggested by the author; it would, of course, not give direction of deflection. Comparing the diamond and chilled shot methods, the latter would appear to be cheaper, but it would seem that difficulty would be experienced in drilling soft or heaving formations by chilled shot if, as mentioned by one of the speakers, the shot were brought out of the hole when using a mud fluid. Even with a rotary the drilling of heaving formations is very difficult unless extra heavy mud is used, and even then progress is often slow. He knew of one well where they had encountered a bad heaving formation in which progress could only be made by the use of large quantities of barytes. He would be glad to know if it would be possible to use such heavy mud with a diamond drill. To obtain economy on a wildcat well he thought the diamond should be used from the top to the bottom of the hole, otherwise a saving would not be effected in the cost of road making and transport charges. He would also like to know how much water was required with a diamond drill per day. Sometimes in a test area springs or streams in the place would not give more than 100 to 500 gallons an hour: would that be sufficient to run a diamond drill 24 hours a day, or what was the total amount of water required per day?

Mr. T. Dewhurst said that he wished to intervene to avoid a false impression being given by the discussion. It seemed to him that the importance of obtaining a continuous core from the surface to the bottom of a well had been somewhat exaggerated. In very many outside areas the geologist knew enough about the stratigraphy to dispense with continuous coring from the surface to the final depth of the hole. In almost every case of which he had knowledge it had been very desirable to obtain continuous cores of a particular range of strata, usually the oil-bearing beds, and occasional cores of other parts of the series in order to obtain evidence in regard to the underground structure. Not only did the amount of coring required to yield evidence concerning the strata depend on previous stratigraphical knowledge of an area, but the amount of coring needed for evidence

of structure depended on the degree of knowledge of the structure previously obtained from surface evidence and section construction. As regards coring to find the crest of an anticline, it was possible in many cases to construct a section from surface evidence giving a rough indication of the position of the crest underground, and it was then possible by frequent coring within a comparatively small range to fix the exact position of the crest in a well. He desired to express the opinion that the supposed great advantage of the diamond drill in giving a continuous core from top to bottom was largely illusory, as he had found in many cases that intermittent coring, with frequent coring within special ranges, with the rotary had yielded all the information that was required. His main point was that there was a certain amount of stratigraphic and structural control of the amount of coring to be done in a well. He was unable to say anything about the diamond drill from the mechanical point of view. It had been invaluable for prospecting for minerals in the harder rocks of the older geological systems, but it seemed to him that the advantage of using diamonds as a cutting agent in relatively soft Tertiary strata might be much exaggerated. The very great advantage of the diamond drill was that it could drill through very small sizes of casing, and for that reason there seemed to be a great field in the future for its use for the sole purpose of deepening rotary wells which otherwise would have reached mechanical finality.

Mr. A. E. Chambers said he could not take the responsibility of answering the many points that had been raised in the discussion. A report of the discussion would be sent to the author and his answers would be published in the Journal. Personally, he had very little to add to the interesting discussion that had occurred. The question of the less weight of the diamond drill for transportation, and incidentally the less weight of fuel that had to be transported, was an important point which did not appear to have been mentioned in the paper itself. He thought it was very satisfactory, as Prof. Illing had said, that an account of a diamond drill, written in this country, was now available, because there was very little indeed to be found out about it in English literature. Mr. Heseldin held no brief for the diamond drill, and had simply described what it could and could not do. The summary at the conclusion of the paper, in which the author expressed his views in regard to the limitations of the diamond drill, was very much to the point.

The Chairman said he was sure it would be the desire of the members that the Secretary should write and convey to Mr. Heseldin

their gratitude for the most interestign and valuable paper he had contributed to the Institution.

The resolution of thanks having been carried by acclamation, the meeting terminated.

The following contribution was received from **Mr. W. J. Wigney** :—

Mr. Heseldin has outlined very fairly the advantages and disadvantages of the diamond drill for oilfield work, but does not appear to offer any grounds for expectation that the diamond drill will become commonly employed in the search for oil in preference to the other systems at present generally used. Its main purposes appears to be to secure geological information, for which it is undoubtedly ideal, but the securing of geological information is not the ultimate object of any operating oil company, although this is, of course, an essential step in the successful development of any presumably oil bearing property. On this account it would probably make a greater appeal to the geologist than to the man whose purpose it is to secure the greatest possible production of oil in the minimum time and at the least expense.

The paper was written in 1927, and the rapid advances made since then and earlier in the rotary system have largely minimised or outstripped the few advantages of the diamond drill. There are many disadvantages in the diamond system of drilling which appear to be inherent in this method and impossible to overcome. In the first place there is the cost of the equipment, which when the cost of diamonds is taken into consideration, is considerably in excess of the cost of a standard rotary outfit for deep wells.

With the diamond system it appears possible to drill small diameter holes only and when depths of 5,000 to 6,000 ft. are being dealt with, which is a depth easily within the range of any high-class rotary outfit, the finishing diameter of the hole must necessarily be so small as to present very considerable difficulties in the subsequent work of raising the oil to the surface and gives very little opportunity for the installation of satisfactory pumping equipment or gas lift devices. Much time would obviously be consumed in reaming the hole to the required gauge after cores had been taken, and also in running in and withdrawing inserted joint or flush-joint casing, which must be used in such small diameter holes in order to allow of a sufficient number of strings being employed. This inserted-joint casing was handled by means of swivel nipples which had to be attached to and unscrewed from every joint of casing as it was lowered into the hole. Considerable time in this direction could, however, be saved by the use of some of the newer types of slip elevators which are now widely used not only on inserted joint casing, but also on collared casing, drill-pipe, etc.

It is certainly less easy to find experienced diamond drillers than rotary drillers, and the setting of the diamonds in the drill bit appears to be work for an expert.

The most interesting advantages claimed for the diamond drill are the possibility of securing absolutely accurate cores and the automatic control of the weight imposed on the drilling bit. These are advantages which are not peculiar to the diamond drill, as they are equally well secured by the ordinary rotary system. Apart from the automatic control devices installed in the transmission between the power unit and the draw-works, there are various weight indicators intended to be inserted in the casing line. The control devices ensure that the weight imposed on the drilling bit is automatically regulated and is immediately relieved should it become too great, while the different forms of weight indicators enable the driller to see what weight is being carried on the bit at any time and to relieve it in the ordinary way should it be too great.

The rotary, of course, drills a much large diameter hole than the diamond drill and permits finishing wells even at depths of 7000 or 8000 feet with a practical diameter to allow production of oil under economical conditions.

With regard to drilling tools, I note that the operations with the diamond drill described employed cone rock bits and disc bits. These are tools universally used with the rotary system in particular formations, but the recent developments in rotary core drills afford probably the most interesting comparison with the two systems. All rotary core drills now used are of the double barrel type, to preserve the core intact without becoming contaminated by mud fluid or damaged through burning. The cutting edges of core drills, and in fact of all other forms of bits and underreamers, are now commonly dressed with some form of hard metal which is either welded to the cutting edge or inserted in the form of small sections, and this work presumably requires less time and does not call for such expert workmanship as setting diamonds in a diamond drill. Also, rotary core drills are constructed to drill the hole to full gauge at the same time as the core is being taken.

The speed of drilling is a factor which has a very great bearing on the cost of operations, and from the tables given in Mr. Heseldin's paper it appears that the diamond drill cannot give anything like the same speeds as can be secured by the rotary system, even in consideration of the much smaller diameter holes which it drills. When coring with the rotary it is necessary to run at a slower speed than when cores are not being taken, but even under such conditions the rotary appears able to make hole at a much better speed than the diamond drill.

There are many other points in the paper which could be enlarged upon in support of the contention that the diamond drill is unlikely to supersede the rotary system in practical development of oil properties, though it is reasonable to suppose that it will continue to fulfil a useful function in the securing of preliminary geological information, on the basis of which plans for the rational exploitation of an oilfiled can be promulgated.

Mr. G. Heseldin wrote in reply :—

In the first place I wish to thank Mr. Chambers for kindly reading the paper for me in my absence and also the members for showing such interest in the paper as revealed in the discussion.

I think that the majority of those taking part in the discussion seem to have rather overlooked the fact that the usefulness of the diamond drill is confined to wildcatting operations ; it can never compete with standard or rotary tools for production drilling. As Mr. Chambers reminded the meeting, this is definitely stated in the summary at the conclusion of the paper.

The chairman had referred to chilled-shot drilling. Personally I would not like to put down a deep test with a shot drill. The shot drill is successful in drilling the harder rocks but falls down badly when it comes to drilling the softer unconsolidated formations. A cutter type of bit is usually used for drilling in these softer beds. Mud fluid cannot be used with a shot drill owing to the tendency of the heavy mud to float the shot out of the hole. I do not think that the shot drill will ever be used to any extent in the oil industry, and I believe it is being gradually displaced from mineral prospecting work.

The cost per foot of a hole depends on many factors other than the medium employed to do the actual cutting of the formation. From figures given in the paper it will be seen that the cost for diamonds was only 6.8 per cent. of the total cost for drilling the well, even with abnormal diamond loss. Speed is the principal factor in reducing drilling costs. It is impossible to compare the drilling speed of two systems in different fields, so the reference to the speed of cable tools in Oklahoma is hardly relevant. Some very good drilling speeds have been obtained by the diamond drill on structure testing work in the same State.

The Chairman had possibly misunderstood the reference to rotary bits. These rotary bits were run on the diamond drill outfit and not on a separate rotary rig. As explained in the paper the rotary bits were used for drilling the upper portion of the holes. A direct comparison between rotary tools and the diamond drill is given in the paper, the comparison being favourable to the latter with certain reservations.

With regard to Mr. Ellis's remarks, I agree that the diamond drill cannot use every conceivable type of bit. Apart from the diamond bit, the diamond drill can operate Hughes rock bits very efficiently, but fishtail bits can only be used in very soft formations. The new drilling outfits have come on the market within the last year or two with the idea of combining the advantages of the diamond drill and the rotary systems. Personally I consider this will be very difficult to accomplish, and believe that the rotary system will continue to be used for the majority of drilling work, leaving the diamond drill to take care of the special jobs. The use of flush joint drill-pipe and a stuffing box will greatly assist the ordinary rotary rig in drilling under pressure. It may interest the members to know that a stuffing box was used on the deep Punjab test. All the hole made was obtained through the stuffing box and the well was perfectly secure at all times.

The reason for drilling the small hole first and afterwards reaming out to set casing, was decided on for several reasons. The small hole can be drilled with fewer diamonds in the bit, hence if anything went wrong, there would be a smaller loss than if a large bit had been used. Again, as a small diameter bit can drill faster than a larger one, there was a great saving of time if the hole could be put down with the small bit without the necessity of setting casing. Finally, if an oil sand was encountered, the hole could be reamed out through the sand, using oil for circulation, thus restoring the walls of the hole to their normal state and getting over the troubles that arise when drilling through a low pressure sand with mud fluid. Reaming out a diamond drill hole is a fairly rapid process.

In reply to Dr. Henderson the writer would beg to remind him that the description of the method for taking deflections was one that was improvised on the spot, naturally there were more refined methods of taking deflections of boreholes but this was outside the province of the present paper. It is my own opinion that the diamond drill is not so liable to drill a crooked hole as a rotary. If reference is made to my paper on the Seminole Field it will be seen that deviations of as much as 25° were observed on rotary drilled holes.

In reply to Mr. Chapman, it is a pleasure to state that only one "twist off" occurred on the diamond drilling work in India. This was at the core shell and was due to the driller burning the bit. The writer had no information on any other alloys than those mentioned in the paper. Personally he was of the opinion that for normal drilling, the cheapest material to use in a diamond bit was the highest grade carbon obtainable. In broken ground or in other cases where there was a danger of breaking the stones, substitutes were justifiable. When drilling alternating soft and

hard formations, it was essential to drill slowly through the soft strata otherwise there was a danger of damaging the stones or twisting off the drill stem when the bit encountered the underlying hard strata, if the bit was fed down too fast.

Mr. Capito's remarks on the question of transport were very much to the point. With the exception of two or three loads the whole of the diamond drill machinery was transported to the Punjab location on camels, a distance of forty miles. The odd two or three loads were moved out in bullock carts. The diamond drill outfit weighs much less than a rotary rig.

Mud fluid was used for circulation, the weight averaging between 75 and 80 pounds per cubic foot.

It was possible by making experiments with weak solutions of hydrofluoric acid to obtain solutions that would not etch the glass before a certain time had elapsed, and which would also lose their etching power after a certain number of hours. The solution and length of setting time varied for each depth. If a correct solution was used it was possible to obtain perfectly etched lines from deep holes.

The greater part of the time taken for the round trip on the deep hole was in coming out, due to the heavy load and the low steam pressure. Running into the hole did not take anything like five hours. By placing several acid bottles at different places in the pipe, a number of readings could be taken from one round trip. The advantage of running the acid bottles on the drill-pipe was that the direction of the inclination could be obtained.

It took about 550 to 600 gallons of water an hour to run this diamond drill outfit and to supply water to the camp. This is much less than a rotary rig requires.

There is no reason why a Barytes laden mud could not be used with the diamond drill.

Mr. Dewhurst's remarks about the number of cores required on a test hole were very interesting. In my opinion it is usually the reverse—the geologists clammer for cores and the drilling department are always trying to dissuade them, so that the drillers can have a chance to make some hole.

I am still of the opinion that if the diamond drill were installed when a rotary hole sets its last string of casing, instead of trying to go ahead using small drill pipe with very small clearance, there would be fewer junked test holes.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS.

THE ONE HUNDRED AND NINETEENTH GENERAL MEETING of the Institution of Petroleum Technologists was held at the Royal Society of Arts on Tuesday, April 9th, 1929, Dr. A. E. Dunstan, President, occupying the chair.

The Secretary announced that the following gentlemen had been elected :—

Members.—Jules Meny, Robert Wingfield Stiles, John Falconer Taylor.

Transference to Member.—Richard Keith Van Sickle, William Joseph Wigney.

Associate Members.—Arthur John George Burton, Arthur George Cahill, Edward Henry Dove, Eric George Ellis, Raymond Noel Kirby, William Littlejohn, Alexander Roy Purves, Harry Nathan Sher.

Transference to Associate Member.—Alexander Erdely.

Students.—Salim Bekhor, John Welford Hyde, Donald Thomas Jones.

Associates.—Albert Edward Johnson, Richard Burton Rogers.

The President said he desired to welcome the reader of the paper, Dr. Dudley Stamp, who had on two previous occasions read papers at the Institution on Burma and its Oilfields, and he was sure the members were glad that Dr. Stamp was continuing his authoritative work on the subject. The members would be even more appreciative of Dr. Stamp's efforts when he informed them that he had stepped into the breach at very short notice, in fact, he had had only three weeks in which to produce the paper which was about to be read.

The following paper was then read :—

The Oilfields of Burma.

By L. DUDLEY STAMP, B.A., D.Sc. (London), A.K.C., F.G.S. (Member).

I.—INTRODUCTION.

ON two previous occasions the present writer has laid before this Institution certain details concerning the petroleum geology of Burma. On the first occasion, two years ago, the title of the

paper was "The conditions governing the occurrence of oil in Burma"[1] and, as the title suggests, the aspect of the subject considered was that of the geology of Burma as a whole and its relation to the occurrence of oil. On the second occasion, a year ago, the oilfields of Burma were used as illustrative examples in some of the general theses considered in "The connection between major structural features and the occurrence of commercial oil deposits".[2] On both occasions the actual producing oilfields of Burma were mentioned but briefly and incidentally. The purpose of the present paper is to consider the oilfields themselves, and it may therefore be regarded as complementary to the first-mentioned paper.

During the four or five years which the writer spent in Burma he had occasion to visit all the producing fields, with one exception. Most of the details which follow are therefore based primarily on personal observation. In 1921–22, as geologist to the Yomah Oil Co. (1920) Ltd.—a small company actually owned by that amazing Chinese the late Hon. Lim Chin Tsong, who achieved fame through the pages of *Punch* at one stage of his career by purchasing a liner for the purpose of a visit to Europe—his first duty was obviously to learn as much as possible, by whatever means, of the activities of the larger companies. Later, many parts of the country, especially in Lower Burma, were studied on behalf of the Indo-Burma Petroleum Co., Ltd., and the writer is indebted to their managing agents, Steel Bros. & Co., Ltd., for permission to publish the main results of these studies. During 1924–26 many journeys and researches were carried out under the auspices of the University of Rangoon.

II.—The Petroleum Production of Burma.

The most important mineral product of India is, at present, coal. But ranking second in value is mineral oil, and the bulk of India's total comes from the Province of Burma. There are, it is true, small oilfields in Assam worked by the Assam Oil Co., Ltd. (Burmah Oil Co., Ltd.) and the Khaur field in the Punjab worked by the Attock Oil Co., Ltd., but the figures here given (Table I.) show the predominating importance of Burma's share. The figures also illustrate the remarkable steadiness in production for many years in succession. It will be seen later that the various fields have not always contributed in the same proportions. When production from one has dropped, another has been steadily developed to maintain output. This policy is still being continued. As long ago as 1908 agreements were reached between the various oil companies concerned and the Government of Burma (which is now regularly represented by the Warden of the Oilfields) to prevent wasteful competition.

Owing to the rapid increase in world production of oil, India's share has shown a steady percentage decrease. In 1912 India's total represented 2.09 per cent. of the world's supply; in 1925 to 1928 it had sunk to less than 0.7 per cent.

Oilfield statistics for Burma are published annually, about ten months after the close of the year, in the "Review of the Mineral Production of India," *Records of the Geological Survey of India*. Every five years a special volume of the *Records* is devoted to a "Quinquennial Review of the Mineral Production of India." The last published embraced the period 1919–23.

TABLE I.

BURMA: PRODUCTION OF PETROLEUM (IN GALLONS).

Year.	Whole of India, including Burma.	Burma.
1888[1]	2,650,000	2,610,000
1889	2,950,000	2,900,000
1890	4,450,000	4,400,000
1891	5,800,000	5,780,000
1892	8,500,000	8,450,000
1893	10,200,000	10,100,000
1894	11,000,000	10,800,000
1895	13,200,000	13,100,000
1896	15,500,000	15,100,000
1897	18,000,000	17,600,000
1898	22,234,438	21,684,963
1899	32,934,007	32,309,531
1900	37,729,211	36,974,288
1901	50,075,117	49,441,734
1902	56,607,688	54,848,980
1903	87,859,069	85,328,491
1904	118,491,382	115,903,804
1905	144,798,444	142,063,846
1906	140,553,122	137,654,261
1907	152,045,677	148,888,002
1908	176,646,320	173,402,790
1909	233,678,087	230,396,617
1910	214,829,647	211,507,903
1911	225,792,094	222,225,531
1912	249,083,518	245,335,209
1913	277,555,225	272,865,397
1914	259,342,710	254,652,963
1915	287,093,576	282,291,932
1916	297,189,787	291,769,083
1917	282,759,523	272,795,191
1918	286,585,011	274,834,556
1919	305,749,138	293,846,129
1920	293,116,834	279,707,170
1921	305,683,227	296,092,057
1922	298,504,125	281,759,169
1923	294,215,053	271,405,947
1924	294,571,692	270,213,003
1925	289,606,542	262,828,930
1926	280,369,326	250,040,471
1927	281,113,909	245,904,044

NOTE.—249 gallons roughly = 1 metric ton of 7 barrels.

III.—An Outline of the Geology of Burma.

In order to provide a clear background for the descriptions of the oilfields which follow, it will be necessary to give a brief résumé of the geology of Burma, although such an account has been previously published in the Journal.

The general geology of Burma is relatively simple and controls the topography to such a marked extent that the natural geographical and geological units in the country closely correspond.

The country may be divided into four parts:

1. *The Eastern Massif of old rocks.*—The whole of the east of the country, including the Shan States and Tenasserim, consists of a massif of hard, old rocks ranging in age from pre-Cambrian to Jurassic. The whole area, with the exception of several old lake basins, has probably been land since the latter part of the Mesozoic. The massif forms a plateau with an average elevation of 3,000 feet. The western edge is clearly defined, being marked by the conspicuous line of hills familiar to every traveller by train from Rangoon to Mandalay. Along this line the Tertiary rocks dip sharply away from the old massif, but the junction is rarely visible.

2. *The Western Fold Ranges.*—In the west of Burma the dominating feature is a great chain of fold mountains. The chain is complex and broad in the north, where it forms the Naga, Chin, and other groups of hills; but southwards it narrows to form the Arakan Yoma. The actual physical structure terminates in Cape Negrais, but structurally the same fold continues through the Andaman and Nicobar Islands into Sumatra. In Burma several peaks reach 10,000 feet. Very little is yet known of the geology of the chain. The structure appears to be anticlinorial, with a central core of crystalline rocks. Triassic, Jurassic, and Cretaceous rocks are involved in the folding as well as the Tertiary sediments on the flanks. There is good reason to believe that the fold originated in Cretaceous or earlier times and grew gradually during the Alpine movements of the Tertiary Period. The fold gave rise to a narrow land barrier from Eocene times onward.

3. *The Central Tertiary Basin.*—Between the Arakan Yoma on the west and the Shan Plateau on the east lies the great region of Tertiary rocks in Burma. It corresponds roughly with the basins of the Chindwin-Irrawaddy and the Sittang rivers, and it is in this region that the petroliferous deposits of Burma are found.

4. *The Arakan Tertiary Region.*—Between the Arakan Yoma and the Bay of Bengal lies another area of Tertiary rocks, forming part of the Assam area of deposition.

In early Tertiary times Burma may be pictured as partly covered by a long, narrow gulf of the sea, with the Shan Plateau forming the land mass on the east and the central ridge of the Arakan Yoma forming a narrow strip of land on the west. This strip of land may have been a peninsula separating the Burma and the Assam areas of deposition, or it may have been a long narrow island. In the latter case the retention of the term "Burma Gulf" is still justified because deltaic or freshwater conditions prevailed at the northern end.

More correctly one might refer to the Burma twin-gulf, for it was divided into two parts by a central, longitudinal ridge. The western portion corresponds roughly with the Chindwin-Lower Irrawaddy region of the present day: the narrower eastern portion with the Upper Irrawaddy—Sittang region. The central ridge may only have been a submerged one, but it was sufficiently important to cause a marked difference in the deposits laid down in the eastern and western parts of the Gulf. All the oilfields occur in the western gulf. The site of the old central ridge is marked to-day by a number of extinct volcanoes and, in the south, by the hills known as the Pegu Yoma.

The whole double gulf must have been broader than appears at the present day, owing to the extensive lateral compression and folding which has since taken place. The gulf was open to the sea to the south, but into the northern end there probably poured several great rivers. Possibly the Tibetan course of the Brahmaputra is a remnant of this river system; at a later stage, rivers of which the Chindwin and the Irrawaddy are the modern representatives took its place. The whole history of the Tertiary period in Burma may be summed up as the story of the infilling of the twin gulf by river-borne sediments from the north and by marine sediments in the south. On the whole, therefore, there has been a spreading of continental conditions from the north, pushing the marine waters farther and farther south. This process is still going on, and year by year the delta of the Irrawaddy encroaches on the shallow Gulf of Martaban.

The gradual infilling of the trough has, however, been interrupted at intervals by lateral folding movements. These movements resulted in the gradual uplift of the Arakan Yoma and, at a later stage, of the Pegu Yoma and other folds. Each movement of folding, however, caused a temporary increase of the depth of the centre of the basin and a consequent return northwards, in the centre, of marine conditions. Thus it is found that the gradual southward retreat of the sea was interrupted at intervals by temporary northward movements which have left their mark as wedges of marine strata tailing out northwards. At the same time there

is marked variation in the character of deposits from east to west, across the gulf, and a certain amount of sediment must have been derived from the denudation of the Arakan Yoma land, whilst littoral conditions must have prevailed along its margins.

These lateral changes have a very definite bearing on the disposition of the Burmese oilfields. It is found that the freshwater sands (*e.g.* Irrawaddian) and freshwater clays, with remains of crocodiles, turtles and mammals, are entirely devoid of oil; the marine clays deposited under comparatively deep water are equally devoid of oil. *All the petroliferous horizons are definitely associated with intermediate conditions. The old idea that the oil-bearing beds of Burma occupy a definite stratigraphical horizon is wholly fallacious.* Not only are all horizons from the middle of the Eocene to the top of the Peguan petroliferous in at least certain points, but the oil in the existing fields of commercial importance is obtained from all horizons from the base to the summit of the Peguan and probably from the higher Eocene. Further, any one petroliferous horizon is found to rapidly change its position relative to lithological or palæontological horizons when traced laterally. Hence Burma abounds with examples of promising structures which have yielded nothing. There can be little doubt that this is due to the oncoming of more marine conditions experienced in any one horizon as one proceeds southwards, or to the oncoming of more continental conditions as one proceeds northwards. Beds on the same horizon as the best oil sands of Yenangyaung are barren marine clays at Minbu or Ondwe, though these localities are only twenty or thirty miles to the south! Similarly beds on the same level as the rich oil sands of Singu are barren sands ten or twenty miles to the north in the Yenangyat area.

Very broadly, the intermediate conditions suitable for oil formation seem to have persisted longest in the very heart of the western of the twin basins, in the neighbourhood of Yenangyaung and Singu. To the south are many excellent structures, but the oil-bearing sands are but minor episodes in a monotonous series of marine clays and shales. To the north the oil sands are but minor episodes in a great series of freshwater clays and sands.

It is not the intention of this paper to deal further with these general geological aspects, since they have been considered at greater length in the paper on the "Conditions governing the occurrence of oil in Burma." Before proceeding to some account of existing oilfields, two points deserve emphasis. One is that the rapid alternation of beds of impervious clay and porous sands which characterises the Peguan almost precludes the possibility of extensive vertical migration of oil. The evidence supports the view that the oil of Burma originated in the beds in which it is now

found and only *lateral* migration has been important. The second point is to mention that the Tertiary sequence of Burma is usually divided into Eocene, Peguan (Oligocene-Miocene, predominantly marine) and Irrawaddian (Mio-Pliocene, mainly freshwater sands). For a more detailed classification, the paper already quoted should be consulted.

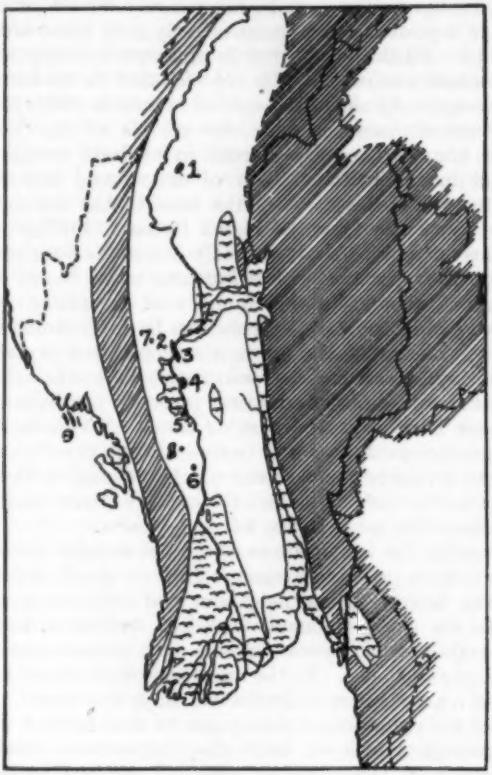

FIG. 1.

MAP SHOWING THE POSITION OF OILFIELDS.

=Indaw; 2=Yenangyat; 3=Singu; 4=Yenangyaung; 5=Minbu 6=Padaukbin; 7=Ngahlaingdwin; 8=Yenanma; 9=Arakan.

The heavily shaded area on the east is the Eastern massif of old rocks that on the west is the Western Fold Ranges.

IV.—The Individual Oilfields of Burma.

Ignoring the small production from the Arakan coastal regions it may be said that there are, at present, eleven producing oilfields in Burma. Arranged roughly in order of their present production they are as follows:—

Production in 1927 (gallons).

1.	Yenangyaung	137,322,012
2.	Singu (structurally includes Lanywa)	98,691,437
3–5.	Yenangyat (Sabè, Yenangyat proper and Lanywa) ..	1,844,946
6–8.	Minbu (Minbu town, Palanyon, and Yethaya) ..	5,199,950
9.	Indaw	1,825,120
10.	Yenanma	999,500
11.	Padaukbin	

The fields of Singu, Lanywa, Yenangyat proper and Sabè, though actually distinct, lie along the same anticline; the two last mentioned are in the Pakokku District and their production is shown as a total only in Government returns. Similarly the fields of Minbu town, Palanyon and Yethaya lie along the same anticline, and, being all in the Minbu district, are considered as one in Government returns. In addition to the eleven fields listed above a twelfth, Tagaing or Minhla, had a small output for a number of years, whilst others have from time to time yielded a few barrels.

1. Yenangyaung.

Yenangyaung is the best known of the Burmese fields, and for that reason will be but briefly considered here. Its picturesque Burmese name, signifying "stinking water creek," or really "oil creek," indicates that the occurrence of oil was known long before the days of the modern oil-industry. Indeed, oil has probably been worked for many centuries, and was certainly being obtained by the Burmans at the end of the eighteenth century. The field was mentioned by Major Michael Symes in 1800[4], by Captain Hiram Cox in 182 [5], and by John Crawfurd (with an account of fossils by Dr. Buckland) in 1829[6]. But the first really scientific observations were made by Dr. Thomas Oldham in 1855 and to Dr. Oldham belongs the honour of being the first to recognise the connexion between anticlinal structure and the accumulation of oil.[7] The Yenangyaung field lay in the independent kingdom of Burma until the annexation of that kingdom to British Burma in 1885.

The early history of the field and its development up to 1909 have been ably summarised by Sir Ernest Pascoe in his well-known work, "The Oil-Fields of Burma,"[8] and there is not much which can be added, apart from details, to his account of the geology of the field. Before the advent of the Burmah Oil Company, large quantities of oil were won by the Burmans from hand-dug wells.

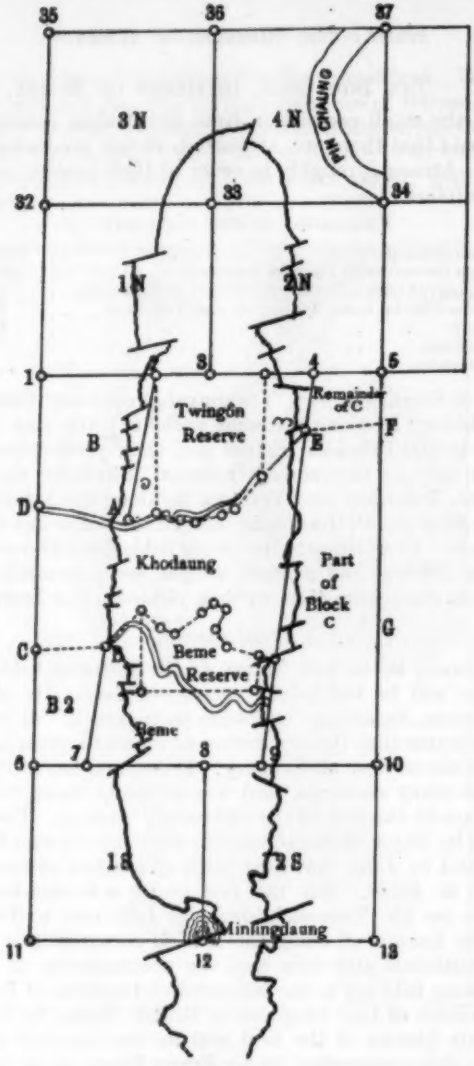

FIG. II.

PLAN OF BLOCKS AROUND THE RESERVES-YENANGYAUNG.

Showing the approximate boundary of the Peguan rocks (shown by black line) and illustrating the strong position of the B.O.C. in Khodaung, and Blocks 1N and 2N and the "sporting chances" still left South of Beme.

Indeed, the table given below shows how important this production has been even until quite recently. The wells were really shafts, 5 feet square, lined with planks, and actually reached depths of over 400 feet. The well-digger was let down by a rope passing over a pulley and he worked frantically for about half a minute in the gas-laden atmosphere before being hauled to the surface for a prolonged rest. Even at the present day a few hand-dug wells survive amidst the forest of derricks. The oil is hauled up by a few coolies running down an incline suitably placed from the well and pulling with them a rope over the pulley. The oil so obtained is sold to the Burmah Oil Company. Such methods of oil-winning are archaic and laborious in the extreme. In the past at least one noteworthy labour-saving device, resulting also in a very marked increase in yield, has been tried. That is the construction of a side gallery from the hand-dug well to the carefully bored pipe of a near-by tube well.

During the Burmese régime two petroliferous tracts—Beme and Twingôn—were worked and the right to mine was granted to twenty-four heads of families known as Twinzayos. A twinzayo could allot sites to any member of his family, but could sell his right only with the consent of the whole body of owners. When Upper Burma was annexed in 1885, the rights of the twinzayos were recognised. The Twingôn and Beme Reserves were demarcated, the former containing 295 acres, the latter 155 acres. By fixing the minimum distance between wells at 60 feet over 4,000 well sites were determined. The wells belonging to King Mindon, which he had acquired by marriage with a female twinzayo or by mortgage, and 27 wells whose owners could not be found, fell to the Crown, and these 164 State wells were leased to the Burmah Oil Company. The Burmah Oil Company was formed in 1886, though their managing agents, Messrs. Finlay, Fleming & Co., had previously traded in oil at Yenangyaung. The first well was commenced in 1887 in Khodaung, and it was not until 1906 that a second producing company appeared. The whole of the production from machine-bored wells between 1888 and 1906 inclusive was the production of the Burmah Oil Co. In the interval, however, the Burma Oil Syndicate had drilled unsuccessfully in the south (Blocks 1S and 2S) in 1890, and a subsidiary of the Standard Oil Company made an unsuccessful attempt to enter the field in 1901. Late in 1906 the Rangoon Oil Company (now a subsidiary of the British Burmah Petroleum Co., Ltd.) began to lease wells from the Twinzayos and commenced drilling and production in 1907. Very soon the competition to secure well sites from the Twinzayos in the Beme and Twingon Reserves became very fierce. It is only in these reserves that competitive drilling is possible; the remainder of the oilfield, or

at least, Khodaung and Blocks 1N and 2N, is leased to the Burmah Oil Company. The price asked by the Twinzayos for their well sites rose rapidly from Rs. 20 to Rs. 100 in 1895 to Rs. 5,000 in January, 1907, and to about Rs. 50,000 in 1910. There are now practically no well sites of value available. In April, 1907, drilling was commenced by Messrs. Jamal Brothers and Co.—whose oil interests were afterwards merged with those of Messrs. Steel Bros. and Co. as the Indo-Burma Petroleum Co., Ltd. Messrs. Steel Bros. & Co., Ltd. remain the Managing Agents of this prosperous oil company, as well as of the Attock Oil Co., Ltd., which operates in the Punjab.[9] The Nathsingh Oil Company was floated in April, 1908, the British Burmah Petroleum Co., Ltd., at a later date (1910).[10] It is unnecessary to more than mention various smaller or short-lived companies such as the Twinza Oil Co. (T.O.C.), United Twinyo, Aungban Oil Company, and Anglo-Burman Oil Co., but of greater vitality is the Yomah Oil Co. (1920), Ltd. The expensive purchase of almost valueless sites by the ill-fated Indo-Burma Oilfields (1920), Ltd. still lives as an unpleasant memory with those who contributed towards the initial £2,000,000 capital of this company. Various syndicates have been interested in various ventures from time to time; in particular the possibility of striking deep oil to the southern end of the field, south of the preserves of the Burmah Oil Company, has always been an attractive speculation. The Eastern Drilling Syndicate[11] put down a deep test in Block 2S about 1921–3.

The oil of Yenangyaung is sent to Rangoon for refining. The Burmah Oil Company have a 10-inch pipe line, 300 miles long, from Yenangyaung to their refineries at Syriam on the Rangoon River. The Indo-Burma Petroleum Co. send their oil by barge or "oil flats" to their refinery, also at Syriam but lower down the Rangoon River. The Yomah Oil Co. and Indo-Burma Oilfields together financed the United Refineries Co., Ltd., and built a refinery still further south along the Rangoon River, but the refinery was closed after a brief life.

Geologically there is little to add to Pascoe's account of the Yenangyaung field. Structurally it is a fine elongated dome. In searching for reasons for the prolific yield and long life of the field, there are several aspects to be considered:—

(*a*) Yenangyaung lies right in the heart of the western of the twin gulfs of Burma, in a position where the 'intermediate' conditions already mentioned as being necessary for oil formation persisted longest. Thus oilsands are worked at all depths from the surface to more than 4000 feet. One may hazard the suggestion that this thickness represents the accumulation of a quarter of a million years.[12] The favourable conditions extended as far north

as Singu, but northwards the beds rapidly become more continental in character. South of Yenangyaung the oil-bearing horizons pass rapidly to barren marine clays and sandy clays on the same horizon (see below under Minbu and Ondwe).

(*b*) The irregularity in the yield of neighbouring wells and the extreme difficulty in the correlation of sands is largely a function of the lenticular nature of the individual oil sands. In some cases a lenticle of sand may really have formed a closed reservoir of oil, and when struck gave a large initial yield which rapidly dropped. Pascoe pointed out, however, that one well might strike an oilsand in a very porous part, so that the flow of oil from the immediate neighbourhood would be at first extremely rapid, resulting in such a diminution of pressure as to affect the yield in a very short time. On the other hand, another well striking the same sand where it was slightly less porous would obtain a smaller initial yield, but one much steadier and declining but slowly. In the good old days this difference explained the sporadic occurrence of spouting wells. Of recent years, when pumping is the inevitable rule, more and more attention has been paid to the question of extracting a larger percentage of the total content from an oil sand. More than once the writer has expressed the belief that the Yenangyaung field is one of the best run fields in the world. Wasteful competition has been eliminated, but not friendly rivalry and a scope for ingenuity. About 1922 for several months one of the companies secured a goodly increase of production of its wells by the application of a little vacuum action. Probably the neighbours suffered but infinitesimally, but conferences, followed by Government regulations, soon secured a uniformity of practice. A later development, at the present in full swing, is the forcing of gas under pressure down a disused hole and getting a distinctly increased production from the five surrounding wells. It is interesting here to note also what a large proportion of the gas is recovered—a proportion rumoured to approach three-quarters. The discontinuity and varying character of individual oil sands have undoubtedly been the real reason for the long life of Yenangyaung. In the words of a well-known geologist, "the patient continues to bear up well, despite the treatment."

(*c*) In the third place perhaps an aspect of the Yenangyaung field which is insufficiently stressed is the large extent of the gathering ground. This has been shown in Fig. 3, and serves at least to demonstrate the importance of lateral migration. As the writer has stressed elsewhere, it is doubtful whether *vertical* migration is anywhere important in Burma.

THE PRODUCTION OF YENANGYAUNG (IN GALLONS).

	Native wells.	Machine wells.
1888	2,548,171	17,468
1889	2,665,998	179,395
1890	2,812,755	1,541,854
1891	2,830,379	2,885,610
1892	2,946,129	5,423,687
1893	3,709,844	6,176,637
1894	3,935,178	6,497,195
1895	4,863,704	7,280,997
1896	5,701,602	7,100,926
1897	5,528,030	8,523,153
1898	5,550,119	8,238,708
1899	4,799,144	14,466,543
1900	8,553,466	19,030,196
1901	6,227,299	30,619,912
1902	7,612,104	33,638,863
1903	7,493,403	49,427,259
1904	7,751,573	65,677,387
1905	8,321,302	77,253,105
1906	8,292,325	81,225,935
1907	7,944,914	88,912,607
1908	7,950,376	115,687,120
1909	5,855,056	181,188,744
1910	174,967,298	
1911	166,494,319	
1912	179,802,842	
1913	200,555,668	
1914	174,981,799	
1915	198,809,315	
1916	240,194,063	
1917	176,979,020	
1918	203,638,043	
1919	190,322,077	
1920	176,285,048	
1921	184,420,141	
1922	179,741,493	
1923	175,158,721	
1924	181,636,739	
1925	160,027,885	
1926	145,731,612	
1927	137,322,012	

Total estimated production of the field to the end of 1928: 3,000,000,000 galls. Of the above figures, 1888-1894 from Noetling's figures: 1895–1909 from official records, quoted from Pascoe; 1910–1927 from official figures. From 1888 to 1906 inclusive the production from machine wells is exclusively Burmah Oil Coy.

2. SINGU.

The Singu and Yenangyat fields lie along an asymmetric fold of Peguan rocks, the axis of the fold running N.N.W. to S.S.E. along a line which would pass, if prolonged, about eight miles to the east of the Yenangyaung fold. The exposed inlier of Peguan rocks is about thirty-nine miles long; towards the southern end the fold is cut obliquely by the Irrawaddy river; south of the river is the Singu field; north of the river the Lanywa, Yenangyat and

Sabè fields. Dr. Thomas Oldham suggested after his visit in 1855 that the oil of the Yenangyat Hills might be worth exploitation and native wells were started some years later, but it was not

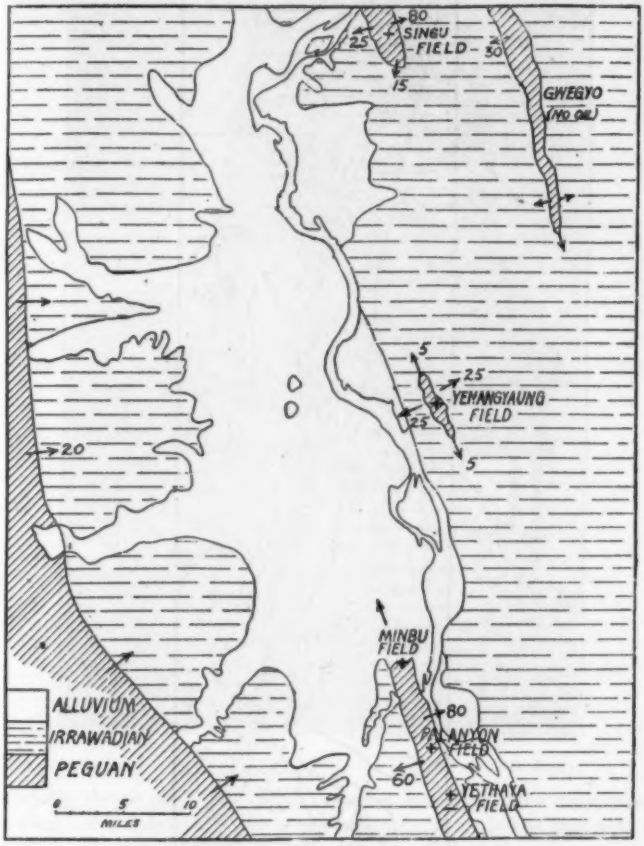

FIG. 3.

until 1897 that G. E. Grimes examined the Singu area and recognised its possibilities—almost the last work accomplished by this intrepid member of the Geological Survey of India before he fell a victim to cholera and died at Thayetmyo. The whole of the Singu-Yenangyat area has been divided into blocks one mile square,

those of Singu are numbered "N" (North) since the whole area from Yenangyaung to Singu was demarcated and numbered.

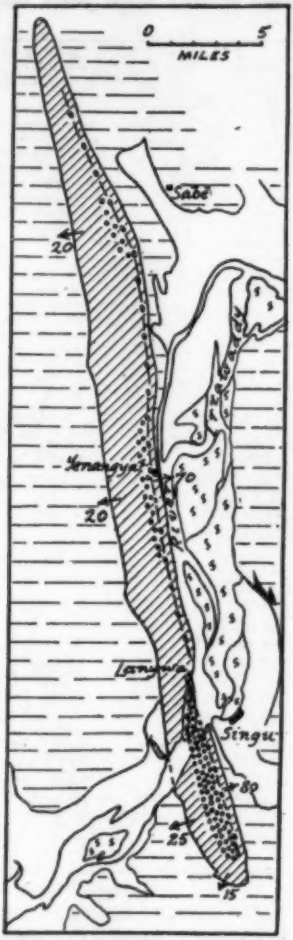

FIG. 4.—Sketch map of the Yenangyat-Singu oil fields, showing the long narrow fold of Peguan rocks (diagonal lines) surrounded by Irrawaddian (horizontal lines). The coarse dots show the approximate limits of the oil fields. The way in which the river Irrawaddy cuts off the northern end of the Singu field is to be noticed; *ss* are sandbanks. The dips shown are generalised and apply to the highest Peguan.

The most valuable part of the whole Singu-Yenangyat area is the southern end—the Singu field. The greater part of the Singu field is leased to the Burmah Oil Co. and has been steadily and

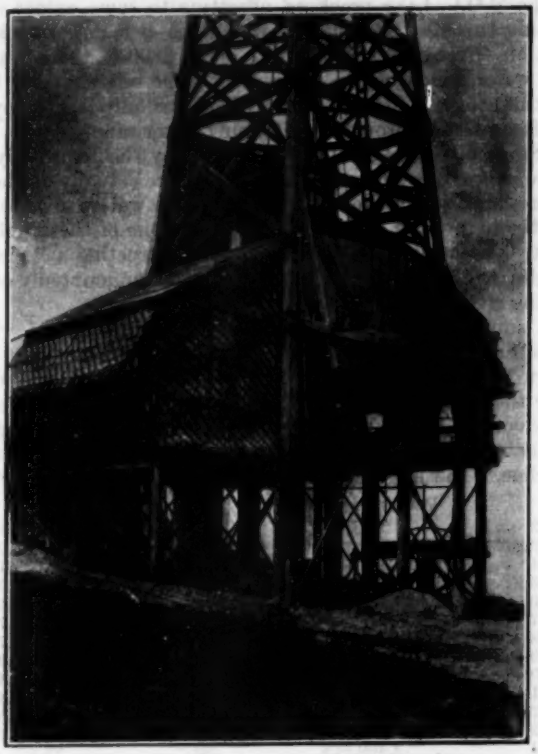

FIG. 5. [*Photo. by L. D. Stamp.*

carefully developed. For some years it has gradually been overhauling the Yenangyaung field and will soon rank as the first field of Burma. It was not realised for many years that the oil measures of the Peguan become steadily poorer from Yenangyaung northwards and that, therefore, at the extreme southern end of Singu a great thickness of rich oil sands might be expected. The Rangoon Oil Co. took up blocks there despised by the Burmah Oil Co. because they were some distance down the somewhat steep (8–20°) southerly pitch, and were rewarded by an important share in a

very rich field. This area is now the main reserve of the British Burmah Petroleum Co. Ltd. The B.B.P. wells have an average depth of 3000–3500 ft. Against the northern edge of the B.B.P. block—54N—the B.O.C. have practised offsetting to some extent. It is interesting to note the depth at which the B.B.P. get their best production—over 3000 ft. Down to about 2800 ft. there is a great deal of water which has to be shut off; the oil sands are below. Hence this southern extension of the field was only located by deep tests, after passing through unpromising water sands.

The Singu oilfield is abruptly truncated by the Irrawaddy river and a number of the Burmah Oil Co.'s wells are actually on the river foreshore and surrounded by the swirling waters of the river during the high-water season. Fig. 5 shows one of these wells and illustrates the use made of old pipes in constructing a "pier" on which the rig can be built. The actual oil field undoubtedly extends under the river.

It is sufficient to say here that, from the point of view of reserves, Singu is the premier field of Burma. Except just at the southern end, the wells are still widely separated and convey at once the true impression that here is a field with huge reserves. As production drops from the sorely taxed Yenangyaung field, so an increased output from Singu may be looked to to balance the decline. The large area held by the B.O.C. is noteworthy.

PRODUCTION OF SINGU (IN GALLONS).

1902	245,390	1915	77,005,880
1903	5,617,371	1916	44,105,013
1904	23,549,759	1917	85,639,166
1905	37,452,055	1918	61,035,982
1906	34,843,621	1919	93,626,506
1907	43,543,566	1920	95,256,753
1908	43,048,948	1921	104,167,749
1909	37,169,061	1922	92,107,998
1910	31,524,175	1923	87,476,474
1911	50,564,755	1924	79,938,430
1912	56,645,200	1925	95,262,519
1913	63,538,710	1926	95,745,504
1914	73,409,518	1927	98,691,437

3. LANYWA.

One of the most interesting oilfields of Burma is undoubtedly that to which the name Lanywa field may be applied. Lanywa is a small Burmese village on the banks of the Irrawaddy obliquely opposite the Singu oilfield and lying in the administrative district of Pakokku. It has already been pointed out that the Singu oilfield is abruptly truncated on the north by the Irrawaddy where that river sweeps from N.E. to S.W. obliquely across the great N.S. fold of Pegu rocks containing the Singu and Yenangyat oilfields. It is undoubtedly certain that the rich Singu oilsands must stretch

a considerable distance under the Irrawaddy. The obvious question of importance is, how far? A glance at the sketch-map, Fig. 6, shows that at this point the change in direction of the River Irrawaddy causes the main stream of the river to hug the Singu shore and to form, as it has already been pointed out, a serious menace

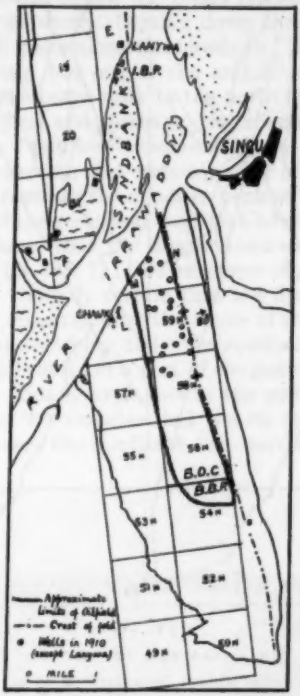

FIG. 6.

THE SINGU-LANYWA FIELD.

Note.—It is probable that the oilpool extends considerably farther south than shown, and may reach Block 52N.

to the B.O.C. wells situated along the shore. As a further consequence a huge sandbank has formed along the opposite shore, a sandbank comparatively permanent in its position and only covered by water for two or three months of the high-water season. In order to ascertain with certainty the northern extent of the Singu oilsand, it is obvious that a well placed near the south-eastern margin of the sandbank would almost certainly be a productive well and might

easily prove a very big producer. Consequently that enterprising company, the Indo-Burma Petroleum Co., as everyone knows, attempted to put down a test well in this position during the few months available between one high water and the next. Ill-luck

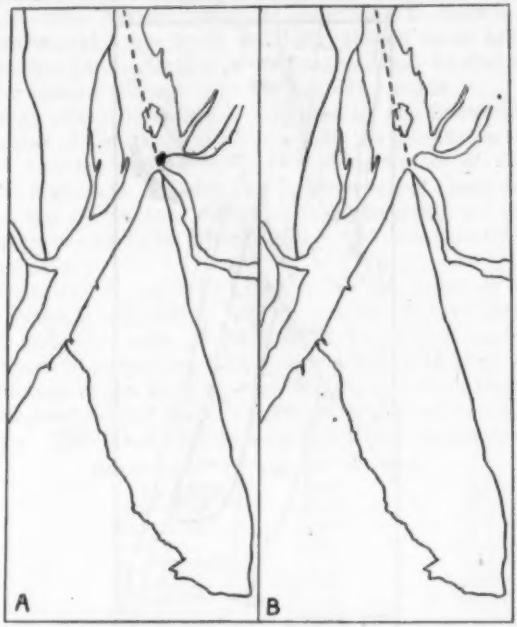

FIG. 7.

DIAGRAMS SHOWING THE CHARACTER OF THE SINGU-LANYWA STRUCTURE.

A shows the Peguan-Irrawaddian boundary as it actually is, and demonstrates that the structure is not a complete dome—*i.e.*, is not closed to the north. If it were closed to the north the boundary would appear as in B.

FIG. 8.

LONGITUDINAL SECTION THROUGH THE SINGU-LANYWA STRUCTURE.

dogged the attempt, the imminent rise of the river level necessitated the abandonment of the test before it had proved anything definite. In the haste of removal the pipe was left in the hole and in the high-water season an Irrawaddy Flotilla steamer ran foul of the

obstruction. Most travellers up and down the river must have heard the story, which loses nothing in the telling. The accident effectively prevented any similar attempts being made and resulted in the Irrawaddy Flotilla Co. having a considerable say in development programmes in the future. An important point which could be settled was whether or not the Singu oilsands extended as far north as the Lanywa shore. Coming down the river the traveller may see four rigs in a line along the foreshore. Three are obviously active and producing, but one of the middle ones appears to be abandoned. The oil-storage tank to the north of Lanywa suggests a moderate production and, perhaps, the abandoned well may be taken to indicate a " patchy " occurrence of oil. The wells are at least significant in showing that certainly some of the Singu oilsands extend even as far north as the opposite bank of the river.

A careful study of the geological maps published by the Geological Survey of India shows that the Singu structure is not " closed " to the north (see Figs. 6 & 7) ; the existence of oil on the Lanywa foreshore makes it virtually certain that the Singu oilsands, or at least some of them, extend under the whole of the great sandbank. One may describe the oil lying under the sandbank as being in part " terrace oil " or oil held up in a part of the anticline where there is little or no pitch. This is explained in the section Fig. 8. It is, therefore, no matter for surprise that the oil company concerned should seek to convert the sandbank into permanent land by the

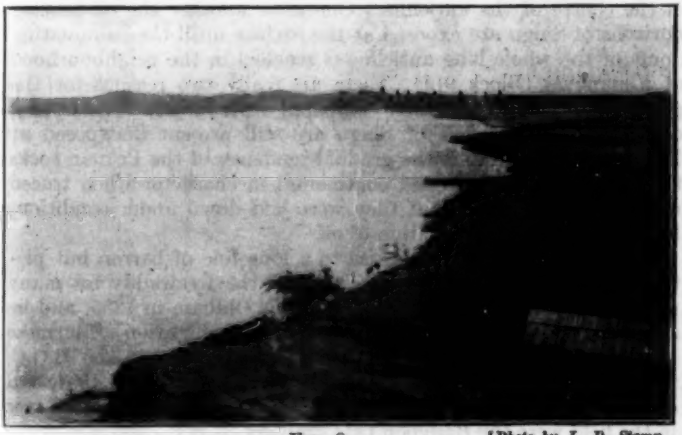

FIG. 9. [*Photo by L. D. Stamp.*

LOOKING SOUTHWARDS ACROSS THE LANYWA SANDBANK BEFORE THE CONSTRUCTION OF THE WALL. THE SINGU FIELD WITH RIGS IS SEEN IN THE DISTANCE

construction of a wall. The Irrawaddy Flotilla Co. would, not unnaturally, oppose any scheme which imposed restrictions on the navigation of the river; the question of scour on the opposite bank and other consequences had to be considered, so that the building of the wall was not commenced till the dry season of 1925-26 and was carried out in three stages—1925-26, 1926-27, 1927-28. The construction of the wall was facilitated by the occurrence of reefs of hard rock jutting out from the shore in the desired direction just where it was desirable the wall should commence, and quantities of stone and rubble were available from other hard bands in the Peguan rocks. Future figures of production must be left to tell the success or otherwise of the scheme.

[NOTE.—In writing the above account of Lanywa, the author has restricted himself to details which could be observed by the ordinary traveller or verified from published records. As a geologist who investigated the scheme he has endeavoured to impart no information which the company concerned might desire to keep secret.]

4.—YENANGYAT.

It has already been explained that Lanywa represents a northern extension, under the River Irrawaddy, of the Singu field. Whether or no the structure at Lanywa is sealed to the north by a small fold is not a question which can be discussed here, but immediately north of Lanywa the outcrop of the Peguan increases in width, the crest of the main fold rises and older and older rocks are exposed in the centre of the anticline. One after another the oil-bearing horizons of Singu are exposed at the surface until the culminating dome of the whole long anticline is reached in the neighbourhood of Yenangyat (Block 9).[13] There are really two reasons for the poverty of Yenangyat when compared with Singu. One is that only the *lower* horizons of Singu are still present unexposed at Yenangyat, the other is the gradual tendency of the Peguan rocks to become more sandy and continental in character when traced northwards—evidence that they were laid down under conditions less suitable for the formation of oil.

The Yenangyat fold gives rise to a long line of barren but picturesque hills forming the right bank of the Irrawaddy for many miles. They were visited by Dr. Thomas Oldham in 1855, and he suggested that the oil might be worth exploitation. Burmese hand-dug wells were commenced a few years later. The B.O.C. first commenced operations around Yenangyat village in 1891, and oil production is officially recorded for the first time in 1893. Later in the field were the Rangoon Oil Company (B.B.P.) and Minbu Oil Company. The story of exploration has been told by Pascoe in his memoir and need not be repeated here. It was gradually found that the commercially valuable field was restricted to the crest

maximum of the fold which is attained in Blocks 9 and 8. Of the valuable area the B.O.C. held Blocks 7, 9, 12; the Rangoon Oil Company Blocks 8, 13, and B. and C.; the Minbu Oil Company Blocks 10 and 33. Many of the wells gave a high initial yield—as much as 30,000 gallons in the first 24 hours—but the yield dropped rapidly just as that of the field as a whole has done. The Yenangyat and to some extent the Singu oils are richer in the lighter hydrocarbons than are the Yenangyaung oils. The B.O.C. oil is sent to Singu by means of a 4-inch pipe-line, Singu being connected with Yenangyaung by an 8-inch line.

PRODUCTION FROM YENANGYAT (IN GALLONS).

	Native wells.	Drilled wells.
1887	37,804	—
1888	44,142	—
1889	44,142	—
1890	44,478	—
1891	47,880	—
1892	51,786	—
1893	45,385	118,409
1894	52,861	283,116
1895	No record	936,016
1896	,,	2,267,451
1897	,,	3,517,839
1898	,,	6,550,422
1899	,,	9,648,069
1900	,,	9,703,129
1901	,,	11,697,001
1902	46,454	8,104,585
1903	36,590	22,631,722
1904	73,676	18,586,809
1905	54,423	17,521,624
1906	66,624	12,508,872
1907	272,065	8,135,760
1908	238,837	6,340,513
1909	210,073	5,769,176
	4,942,308	
1910	4,476,074	
1911	4,880,422	
1912	5,499,191	
1913	4,516,685	
1914	4,099,345	
1915	5,310,740	
1916	6,620,908	
1917	4,739,587	
1918	4,123,387	
1919	3,176,231	
1920	2,510,533	
1921	2,413,416	
1922	1,700,035	
1923	1,594,517	
1924	1,562,444	
1925	1,778,041	
1926	1,844,946	

From 1907 a small production from Sabè is included; from 1921 a small production from Lanywa.

5.—Sabè.

In the northern part of the Singu-Yenangyat fold there is another crest maximum west of the village of Sabè, in Blocks 57, 60 and 67. The B.O.C., R.O.C., and M.O.C. were all interested in the field, but a few initial high yields rapidly declined, heavy gas was encountered, and this is one of the regions of Burma which has been troubled by a yield of emulsion. The field has never been important; its small production, which was first recorded for 1907, is included in the figures just given for Yenangyat. Though structurally distinct, the fields of Lanywa, Yenangyat and Sabè all lie in the Pakokku District, and their productions are not, therefore, separately recorded in Government returns.

6.—Minbu.

The whole Minbu fold resembles the Singu-Yenangyat fold in that it is a long, asymmetric anticline of Peguan rocks with a north-south trend—about 20 miles in length. Along the fold are three oilfields—one, Minbu town or Minbu proper, is at the northern end and occupies a curious position some distance down the pitch; a second corresponds to a crest maximum near the village of Palanyon; a third corresponds to another crest maximum south-west of the village of Yethaya.

In the description of Yenangyat, two reasons were given for the increasing poverty of the Peguan when traced northwards. In the case of the Minbu fold there are three main reasons for its poverty when compared with Yenangyaung to the north. The first is the lithological change in the rocks—the marked increase in the proportion of clay laid down in deeper water and less suitable for the formation or retention of oil, a change still more marked in the Thayetmyo District further south. The second is the same as that given in the case of Yenangyat—the greater thickness of Peguan exposed and the fact that many of the higher petroliferous horizons have been denuded away. The third is the more intense folding—the rocks are frequently vertical and even overfolded on the eastern limb.

An account of the early exploration of the field, up to 1910, has been given by Pascoe and need not be repeated.

Taking now the first and most important of the three fields, the northernmost one, it is in many ways a geological anomaly. Just south of Minbu town the whole fold is crossed obliquely from south-west to north-east by a large fault, and along this fault the famous mud-volcanoes of Minbu are situated. It is probable that the fault effectively seals off the northern end of the fold. North of it there is a domed structure (the Minbu dome) worked by the

B.O.C. in Block 2N. The chief oilsands are at 450 to 750 feet—that is, they belong to horizons denuded away further south. The Minbu Dome pitches northwards at the steep angle of 12° to 15°, and one would think there were no further prospects northwards. Indeed, it was not considered necessary to demarcate blocks north of Minbu town, nor did Pascoe map this area in detail. But a mile or two north of Minbu the northerly pitch changes from 12° to about 6°, and *this change in pitch has been sufficient to hold up an oil pool* on the sort of sloping terrace so formed. At the same time the crest of the fold is duplicated. The B.B.P. work the western half in Block 19P (about 20 shallow wells), the Y.O.C. the eastern half in Block 20P. The oil pool has an area of about 40 acres, and stretches into the northern end of the B.O.C. Block 2N, where the B.O.C. had about a dozen wells—all shallow and drilled with a light Leidecker machine about 1911–1912. Many of the shallow wells came in at 30–40 barrels; maintained 4 or 5 barrels for a long time, only gradually declining. To the best of the writer's knowledge several of the wells merrily yield a few tins of oil a day after a life of a dozen years. When the writer was living at Minbu in April-May, 1922, the Y.O.C. wells were all linked up to one engine which pumped the lot at once for a couple of hours a day. The field is of great interest, not because of any large yield of oil, but because of the important effect of a slight change in pitch in affecting the holding up of an oil-pool.

7.—Palanyon.

South of Minbu, the main fold rises steadily to a crest maximum or dome near Palanyon. After extensive exploration in various parts of the fold (see Pascoe's memoir) the B.O.C. located, and are still working, the Palanyon structure. The oil is, of course, at a much lower horizon than that at Minbu town and occurs at horizons probably 3,500–4,500 feet below the top of the Peguan.

8.—Yethaya.

South of Palanyon there are several slight crest maxima in the main fold, but a well-marked dome is developed towards the southern end. The field is worked by the B.O.C. and is named after a village some distance to the north-east.

Although Minbu town, Palanyon and Yethaya are really entirely distinct fields, they all lie in the Minbu District, and the productions are not separately stated in Government reports. When Sir Ernest Pascoe wrote his memoir in 1910 only small quantities of oil had been obtained, and production is first officially recorded for that

year. The figures given below show that the three fields never have been large and the production, after steadily declining, is showing a tendency to rise:—

PRODUCTION AT MINBU, PALANYON AND YETHAYA (IN GALLONS).

1910	.. ..	18,320	1919	.. ..	4,423,361
1911	.. ..	632,458	1920	.. ..	3,835,198
1912	.. ..	3,896,365	1921	.. ..	3,706,831
1913	.. ..	3,198,311	1922	.. ..	3,940,416
1914	.. ..	1,683,190	1923	.. ..	3,915,140
1915	.. ..	2,316,207	1924	.. ..	3,829,044
1916	.. ..	2,043,542	1925	.. ..	3,248,566
1917	.. ..	3,468,382	1926	.. ..	4,533,420
1918	.. ..	4,826,735	1927	.. ..	5,199,950

9.—INDAW.

Indaw, the northernmost field of Burma, was unknown when Pascoe wrote his memoir. It was discovered rather more than a dozen years ago by the geologists of the Indo-Burma Petroleum Co., Ltd., and production is first recorded officially for 1918. There is no doubt that the discovery caused considerable surprise. Indeed, when experimental drilling was commenced it is said that a well-known geologist—a member of this Institution—volunteered to drink every drop of oil which would be obtained. His dose to date would be about 14,000,000 gallons. The reason for this scepticism is not far to seek. That the Yenangyaung and Singu oil horizons rapidly became poorer northwards when traced through the Yenangyat fold was already known and, if this change persisted, it seemed impossible that a field could be found in Peguan rocks so far north —175 miles north of Yenangyat. Although the gradual infilling of the Burmese Gulf from the north, already mentioned under geology, is in general true, the story is not altogether a simple one. Numerous unconformities exist in the Chindwin area amongst the Tertiary rocks, and whilst Indaw is a fine open dome in the midst of the main Chindwin syncline (on a smaller scale thus comparable with Yenangyaung in the Irrawaddy valley) it is probable that conditions were locally suitable for the existence of oil formation in the Peguan, around Indaw, but not in neighbouring areas of the Chindwin.[14]

Structurally Indaw is a fine, gently folded, open dome, and the field has great possibilities since production up to the present has been from shallow sands. Deep testing has been hindered by drilling difficulties and heavy gas. Indaw is situated in the wet zone of Upper Burma, north of the Dry Belt, and health conditions have caused much trouble, but active measures have been taken to combat fever. Indeed, it fell to the geological staff to study, even more than they are compelled to do at all times, the habits of mosquitoes.

The company has followed the policy of steady development; the oil is sent by pipe line and refined at Pantha (22 miles distant) on the River Chindwin, whence it is sent down the river and supplies the local markets of Upper Burma—the chief product being kerosene for burning. One of the local difficulties is the shipment of the oil in the low water season when the Chindwin becomes very shallow. The large, flat bottomed stern-wheelers of the Irrawaddy Flotilla Company only draw 18 inches when fully laden, but even then often spend days on sandbanks. The production at Indaw is shown in the following figures :—

	Gallons.		Gallons.
1918	473,800	1923	1,311,664
1919	1,085,030	1924	1,474,898
1920	1,022,766	1925	1,385,977
1921	1,182,782	1926	1,255,840
1922	1,210,914	1927	1,825,210

The rocks in the central trough of the Chindwin basin are unconsolidated sands with pebbles and pebble beds, which lithologically resemble the Irrawaddian farther south and are roughly of the same age. Underlying these and exposed on the Indaw dome are the equivalents of the Peguan—it is from the lower members of these that the oil is obtained.

10.—Yenanma.

Yenanma is a remarkable little field which stands alone among the Burmese fields. It seems, on superficial examination, to consist of a pocket of oil-bearing sands situated in the midst of a group of laminated sands and clays forming a homocline (or monocline) with a steady easterly dip of 20° to 25°. However, as explained by Murray Stuart,[15] it is believed by some that these beds are thrust westward over folded rocks of similar or rather earlier age. Dr. Stuart considers that the oil pool actually lies in the fault plane, though the sections he has published show a hidden anticline lying below the thrust plane. It must be mentioned that this conception of the structure is not shared by many geologists who know Burma thoroughly well. Following along the outcrop of the Yenanma beds seepages may be traced for a distance of some 40 miles northwards on two distinct horizons, one near the base of the Peguan and the other some 2,000 or 3,000 feet lower, on the higher part of the Eocene. The northern part of this area will be mentioned later under the heading "Western Minbu." Whether the Yenanma oil is held up in the thrust plane or occurs as a pocket in the normal sequence, there may be similar pockets elsewhere below the monocline but there would seem to be no indication whereby they can be located.

Yenanma was the very first of the Thayetmyo areas to be tested by the B.O.C.—probably before any definite geological investigation, and over a quarter of a century ago. Three wells were drilled, one on the outcrop of the oil sand about 2 miles west of Yenanma village, the second and third to the north and down the

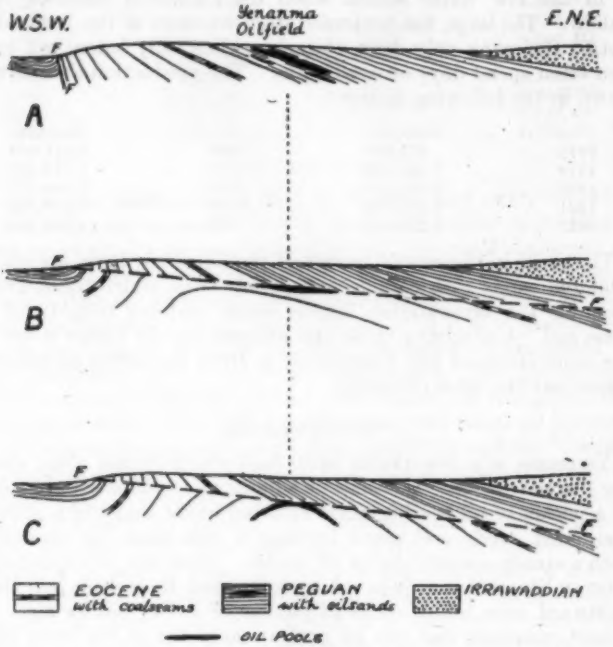

FIG. 10.

DIAGRAMS SHOWING THE STRUCTURE OF THE YENANMA FIELD.

A. The Author's interpretation. B. Dr. Murray Stuart's reading. C. An alterative of the last.

dip, the second in such a position that it would tap the oil sand at about 850 feet. The modern exploitation of the area dates from the advent of the I.B.O. and pumping was commenced on January 12th, 1922. About two dozen shallow holes were drilled, averaging from 600 to 800 feet in depth, some distance to the east of the outcrop of the oilsand which can be examined in a stream course. The locality is comparatively close to Yenanma village and the horizon is not the same as that referred to in the B.O.C. tests, which

is a lower horizon. The producing wells are all in an area of a few acres, those giving the largest production being in the centre of the group. The striking of such a pool is obviously a matter of luck, and it is no cause for surprise that a wildcat well was started at Kyaukpon, some distance to the north. It had only gone down a few hundred feet when the writer was there in May, 1922. The production from Yenanma has been :—

	Barrels.		Barrels.
1922	54,295	1925	27,000 (approx.)
1923	36,649	1926	17,000 (approx.)
1924	33,854		

This is wellhead production recorded by the company. The Government returns for the whole Thayetmyo District, including both Padaukbin and Yenanma, with probably a few gallons from elsewhere, are as follows :—

	Gallons.		Gallons.
1922	2,319,835	1925	1,320,009
1923	1,818,584	1926	974,620
1924	1,717,653	1927	999,500

11.—Padaukbin.

In a later section a number of abortive tests in the Thayetmyo district will be mentioned. These were situated on various anticlinal or domed structures (excluding the Yenanma belt just considered) but the only one which has developed into a field is that of Padaukbin, about 9 miles west-north-west of the important town of Thayetmyo. That the Peguan rocks become more clayey, of deeper water facies and therefore devoid of oil, when traced southwards from Yenangyaung has now been made apparent from the account given of Minbu. In the Thayetmyo district the Peguan is predominantly shaley and the writer has stated the succession to be :—

Upper Sandy or Mixed Group.
Middle Shales (Sitsayan Shales).
Lower Sandy or Mixed Group.

The Lower Group is the horizon of the Yenanma oil, but in the great mass of the Sitsayan Shales there are sandy intercalations. One of these minor sandy groups is exposed at the crest of the Padaukbin dome, one somewhat lower is the oil bearing horizon. The accompanying sketch-map and section, Fig. 11, based on the detailed survey carried out by Mr. T. R. H. Garrett for the Premier Oil Co., shows that the structure is excellent.

The B.O.C. tested the area by means of eight wells about 1905–8. The first wells were clustered to the south-east, around the region marked A on the sketch. No. 1 was right on the crest, No. 2 badly situated to the east where the dips are steep, No. 3 was 800 feet

west of the crest and struck a good sand at 150 feet which, however, soon gave out, but the well was taken lower and reached a gas sand. Nos. 4 and 6 were 1,400 feet west of the axis, Nos. 5 and 8

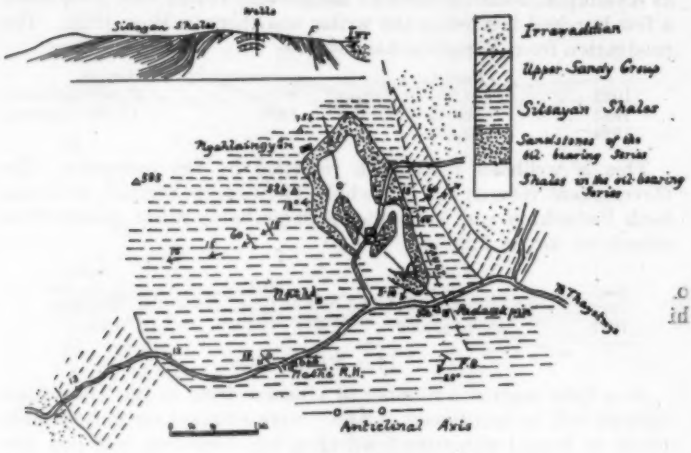

FIG. 1.

SKETCH MAP OF THE PADAUKBIN DOME.

nearly half a mile and No. 7 one-and-a-half miles. With the exception of No. 3 the sites were not very well chosen, but the whole testing was carried out before the adequate organisation of the B.O.C. geological staff. At a later date a number of Burman wells were drilled, two reaching 80 and 150 feet, and were baled at intervals. The second phase in the history of the field was its exploitation by the Indo-Burma Oilfields (1920), Ltd., 18½ square miles at Padaukbin being mentioned in the prospectus of the company. Pumping started on March 7th, 1922, and the production as recorded by the company has been as follows:—

	Barrels.		Barrels.
1922	13,524	1925	14,000 (approx.)
1923	16,079	1926	17,000 (approx.)
1924	15,208		

This is wellhead production and hence greater than the production (on which royalty is paid) shown in Government returns. About 20 wells were drilled about the area marked B in the sketch map and hence well log[illegible]. Many were started with 17-inch casing

with the idea of carrying out a deep test but accidents intervened and it is understood that no well reached more than 1700 or 1800 feet.

Although quite a useful little field, the production is negligible when compared with what would be required to make a paying concern of a company like the I.B.O. with an initial capital of £2,000,000. The Premier Oil Co. came into the field at a later stage as the principal holders of the debentures later issued by the I.B.O.

V.—The Search for Oil in Burma.

One occasionally sees references to Burma as a land whose oil resources are very imperfectly explored. Only two or three years ago an article was published in a monthly technical journal purporting to show the large areas of the country which remained unexplored. The map illustrating the paper actually showed the oil occurrences known in 1909 or 1910, when Pascoe was writing his "Oil Fields of Burma," and even completely ignored the fully developed oilfield of Indaw. Actually the whole of the Tertiary region of Burma—that is, the region where oil might occur—is geologically comparatively well known. Considerable areas have been mapped on the one-inch scale by the officers of the Geological Survey of India, though their maps only show the broad outlines of the geology since the Pegu (10,000 to 15,000 feet in thickness) is not subdivided. The three principal oil companies have also each independently mapped the greater part of the Tertiary area on a one-inch scale. The distribution of oil depends so largely on lithology that the oil companies map in detail lithological groups, although they may be but local. Where a promising structure appears in beds which are, or may be, petroliferous the geology is mapped on a larger scale. The scale adopted by the Burmah Oil Company is eight inches to the mile, topographical maps being specially constructed for the purpose.

But exploration for oil does not end with geological mapping, and in Burma the connections between oil deposits of commercial importance and geological structure are by no means straightforward. On the one hand Burma abounds in perfect structures which have been proved by the drill to be barren. It would be difficult to find a better example than the fine, open, oval dome of Ondwe, which might well have been a second Yenangyaung. On the other hand, several of the producing fields are, speaking geologically, not on very good structures. The Minbu town field lies on a "terrace," which interrupts the northern pitch of the main field; the British Burmah Petroleum Co.'s property at Lanywa is well down the southern pitch of the main fold. Yenan[illegible]ich though inadequate

as the main field of a £3,000,000 company, has produced a useful quantity of oil, yet structurally is less promising than twenty other areas which have been tried unsuccessfully. Such country calls for the closest geological scrutiny and has proved that whereas country appearing good on the surface may fail, the drill may locate at least certain supplies in poor structures. This explains the continued drilling activity in a country which has been fairly minutely studied.

In the pages which follow some account will be given of a number of exploratory bores. The catalogue is nothing like complete, but the list will serve to illustrate the variety of areas and types of occurrence which have been tested.

1. The Pegu Yoma and Paukkaung.

The north-south range of forested hills which stretches from the ancient volcanic pile of Mount Popa in the north to Rangoon in the south, consists almost entirely of folded Tertiary sediments of Peguan age—the rocks which are elsewhere the oil bearing strata of Burma. In the heart of the hills the rocks are tightly and irregularly folded—as is exemplified in the sections exposed along the new railway from Pyinmana to Taungdwingyi—but on the western flanks numerous spurs are given off, each of which consists of a single anticline detaching itself from the main mass and gradually fading away into the plains of Irrawaddian sands or stretches of alluvium. The broad relationship of the axes of these lateral folds to the main chain is shown diagrammatically in Fig. 12. There is little or no sign of oil in the heart of the Pegu Yoma—which coincides with the old ridge separating the two halves of the Burma Gulf—but oil shows are not infrequently associated with the lateral folds. The writer had occasion to map in detail, on the scale of six inches to the mile, the Paukkaung fold and it will serve to illustrate the character of the lateral spurs in general. An anticline detaches itself from the main folded mass and trends roughly E.S.E.—W.N.W. before changing direction abruptly to S.S.E.—N.N.W. and gradually dying away. Like most Burmese folds, the western limb is comparatively gently inclined, only near the sudden bend are dips of up to 80 degrees recorded, but the eastern limb is steep, even vertical or overfolded. The fold consists of Peguan rocks flanked by Irrawaddian. The sudden bend is accompanied by considerable faulting and quantities of oil have been trapped in the region of the faults. Burmese hand dug wells regularly obtained several tins a day for some months. Yet the faulted region is only an interruption of a steady pitch. Is there any use in drilling to the north of the faulted area, in the hope that a considerable pool has been held up? The Yomah Oil Company in 1921 put down a well

FIG. 12.

DIAGRAM SHOWING THE RELATIONSHIP OF THE LATERAL FOLDS TO THE MAIN PEGU YOMA. HEAVY LINES REPRESENT ANTICLINAL AXES.

roughly where shown on the diagram, but rather on the supposition that they were testing a structure closed to the south. This belief was based on a cursory examination by two Japanese geologists. The well was, in any case, badly located and merely ran down a belt of clay in the vertical limb of the fold so that early in 1922 the

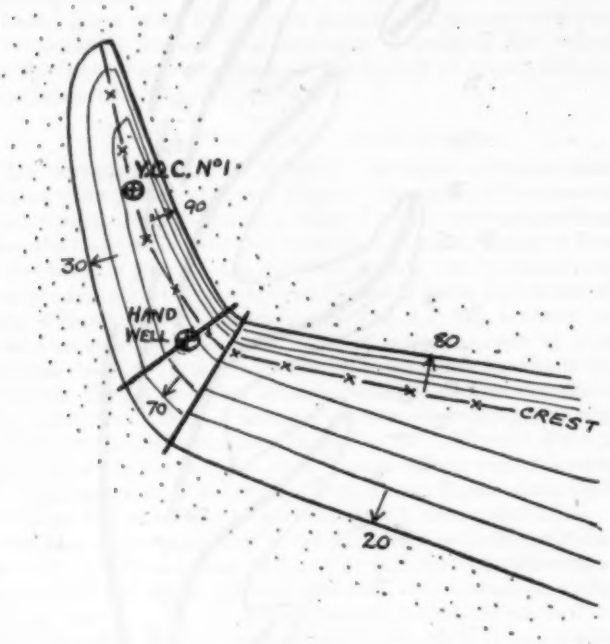

FIG. 13.—DIAGRAM OF THE PAUKKAUNG FOLD.

writer advised its abandonment. It is highly probably that most of the oil in the structure had accumulated in the faulted region and could be best recovered from a hand dug well. Further to the south or east any oil originally present must have completely seeped away.

Similar structures on the flanks of the Pegu Yoma have been carefully examined at numerous areas but have not been sufficiently promising to drill.

2. The Thayetmyo District.

Paukkaung was an example of a structure on the western fringe of the Pegu Yoma. About the same latitude, but in the centre of the great Irrawaddy valley, there are numerous folds of Peguan rocks, varying from perfect closed domes with gentle dips to faulted, or overfolded anticlines. There are almost innumerable structures which might be drilled, whilst numerous seepages of oil and gas shows are present to encourage prospecting.

The history of the oil exploration of this region falls into three periods :—

(*a*) The early prospecting and testing by the Burmah Oil Company when the policy was to drill a number of shallow holes. Several of the earlier holes were made with very little geological investigation and were located near oil shows. Yenanma was tested thus in the early years of the present century, Padaukbin a little later.

(*b*) The later prospecting and testing by the Burmah Oil Company which dates from the re-organisation of their geological staff. A very thorough geological investigation—associated with the names of Mr. Cunningham Craig, Mr. James, Mr. T. Dewhurst and Mr. G. W. Lepper—preceded testing of promising areas by means of single deep wells. The testing was carried out about the period 1910-1916. The results were considered insufficient to warrant further expenditure and the Burmah Oil Company withdrew from the whole area.

(*c*) The post-War period of re-examination by numerous companies, including the Indo-Burma Oilfields (1920) Ltd.; the British Burmah Petroleum Co., Ltd.; the Indo-Burma Petroleum Co., Ltd.; the Premier Oil Co. Ltd., the Yomah Oil Co. (1920) Ltd., Union Oil Co. Ltd. and others. The first-named succeeded in getting the small fields of Yenanma and Padaukbin already described—sufficient to arouse lively interest in the whole region once again. The British Burmah Petroleum had an interesting little strike about 6 miles west of Thayetmyo in 1925, whilst Pyayè (Indo-Burma Petroleum Co. Ltd., 1924-8) can probably lay claim to being the biggest gas field in Burma.

The geology of the whole area can be but briefly mentioned here. In the west, forming the foothills of the Arakan Yomas, there is the main outcrop of the whole Peguan Series, dipping steadily eastwards and attaining a thickness of 12,000 to 16,000 feet. Along this belt of evenly dipping strata lies the Yenanma Oilfield. Between this

belt and the River Irrawaddy are numerous folds of Peguan rocks surrounded by the later Irrawaddian. From the point of view of oil the more interesting structures are :—

(1) *Banbyin.*—This is an irregular anticline with oil seepages from outcropping sands on the crest of the fold, and some oil was obtained from a hand-dug Burman well. The Burmah Oil Company put down five shallow wells, near the crest. No. 1 was just west of Banbyin village, Nos. 2 and 3 1200 feet further south, Nos. 4 and 5 just east of Kadaing village. Apparently no oil shows were obtained in any of them. The test was an early one, made after Yenanma and Padaukbin.

(2) *Kyawdo.*—This promising sealed dome was carefully surveyed by the Burmah Oil Company before a deep test was commenced in 1911, and was taken to 3,628 feet (then about the deepest hole in Burma), the work occupying over two years. Faint shows were struck at 1463 feet, 1637 feet, about 2300 and a good one at 2627 feet (reckoned as good for 2 or 3 barrels), but the gate-valves optimistically shipped to the site were never used and the hole was eventually abandoned.

(3) *Yinaing.*—This is a small dome south of the Kyawdo area, somewhat irregular in character, and was tested by the B.O.C. by two holes in 1911–1912. These reached 900 and 600 feet and no oil shows were found.

(4) *Mónnatkôn.*—This is another closed dome. After careful geological investigation the B.O.C. drilled a hole to 1550 feet. A second hole was taken down to 1240 feet and then to over 3000 feet by rotary drilling. This well is interesting as being one of the early examples of experimental rotary drilling in Burma, being carried out in 1912–13, although rotary had previously been used at Singu.

(5) *Thayetmyo-Padaukbin Road.*—This structure brings one to the era of recent developments. It is a small terrace, one might almost say a pimple, on the nose of a pitching anticline. A well put down by the B.B.P. in 1924 struck oil unexpectedly about 500 feet and drilling was immediately suspended. The strike caused a considerable amount of consternation; the site is close to the main road—a metalled motor road—from Thayetmyo to Padaukbin, and was passed daily by the geologists of the I.B.O. and Premier Oil Companies. The writer confesses to having passed over the ground without noticing the irregularity of pitch. But the possible gathering ground is only a few acres, and that the "well" was short-lived is no matter for surprise. None of the subsequent wells obtained oil.

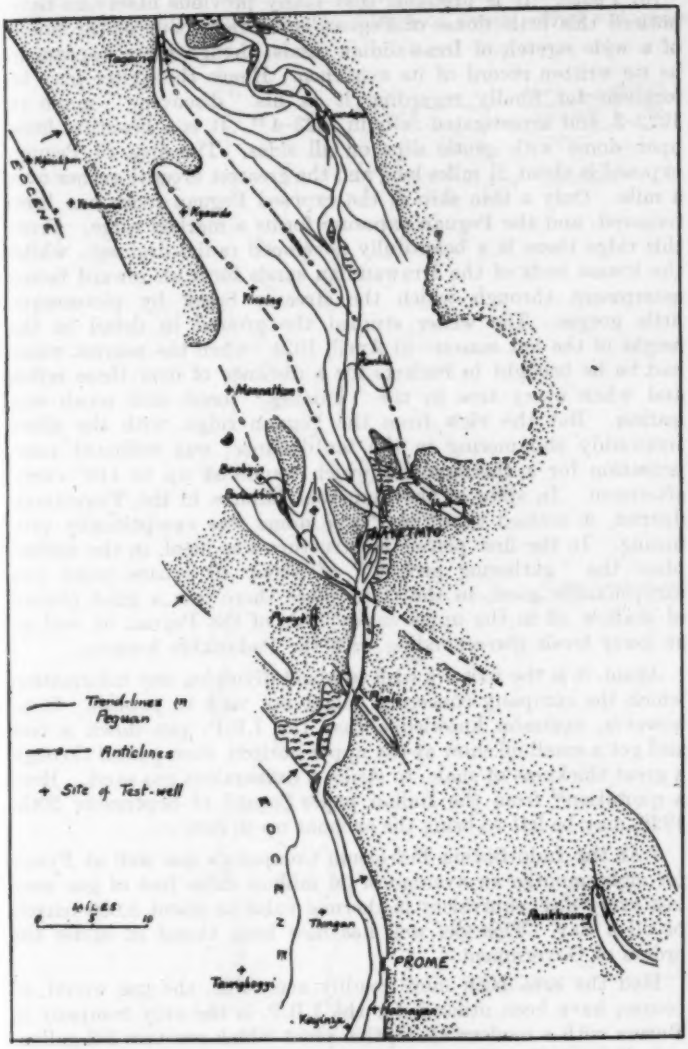

FIG. 14.

SKETCH MAP OF THE THAYETMYO DISTRICT SHOWING LOCATION OF OIL TESTS.

(6) *Pyayè*.—It is probable that many previous observers have noticed this little dome of Peguan rocks rising out of the midst of a wide stretch of Irrawaddian sands, though there appears to be no written record of its existence. Hence the writer may be forgiven for fondly regarding it as his "discovery" made in 1922–3, and investigated fully in 1923–4.[17] It is a beautiful little open dome with gentle dips on all sides. The area of Peguan exposed is about 2½ miles long and the greatest breadth rather over a mile. Only a thin skin of the exposed Peguan rocks has been removed, and the Peguan exposure forms a marked ridge. From this ridge there is a beautifully developed radial drainage, whilst the lowest beds of the Irrawaddian sands form an inward facing escarpment through which the streams break by picturesque little gorges. The writer studied the ground in detail in the height of the hot season—in April, 1924—when the nearest water had to be brought in buckets for a distance of over three miles, and when every tree in the "indaing" forest and scrub was leafless. But the view from the Peguan ridge, with the silver Irrawaddy shimmering in the far distance, was sufficient compensation for a thermometer which wandered up to 110° every afternoon. In spite of the numerous failures in the Thayetmyo district, it seemed that the Pyayè dome was exceptionally promising. In the first place, the structure was ideal, in the second place the "gathering ground" of about 40 square miles was exceptionally good, in the third place there was a good chance of shallow oil in the upper sandy beds of the Peguan as well as at lower levels corresponding with the Padaukbin horizon.

Again, it is the writer's wish to avoid divulging any information which the company concerned might not wish to publish. It is, however, common knowledge that the I.B.P. put down a test and got a small oil show at the upper horizon, then passed through a great thickness of shale, to strike a tremendous gas sand. Here a quotation[18] from the Indian paper *Capital* of September 20th, 1928, may be left to bring the account up to date:—

"At the Indo-Burma Petroleum Company's gas well at Pyayè for eight months an average of 30 million cubic feet of gas were lost every day, equivalent in thermic value to about 5,000 barrels of oil a day. This gas well has now been closed in under the orders of Government."

Had the area been more readily accessible, the gas would, of course, have been utilised, for the I.B.P. is the only company in Burma with a modern absorption plant which recovers 2.2 gallons petrol per 1000 c.ft. of gas.[19] The old compressor plant of the B.O.C. only gives a return of 1·3 gallons per 1000 cubic feet of gas.[20]

(7) *Pyalo.*—This extensive and deeply denuded fold crosses the River Irrawaddy near the large village of Pyalo. Mud volcanoes

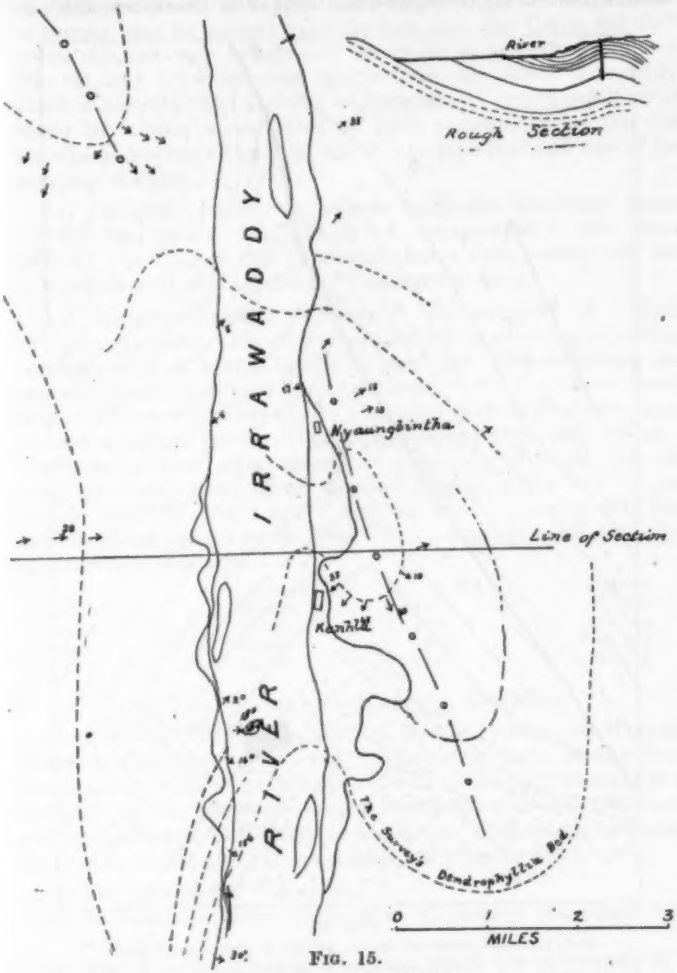

FIG. 15.
THE KANHLA STRUCTURE.

and gas-shows occur, and the area was tested by the B.O.C. some years ago. A shaft was also put down by Messrs. Jamal Bros.

(8) *Thanat.*—This open fold lies east of the river and north-east of Thayetmyo. After an examination of the area by Messrs. Cunningham Craig, Dewhurst and Lepper in December, 1910, and

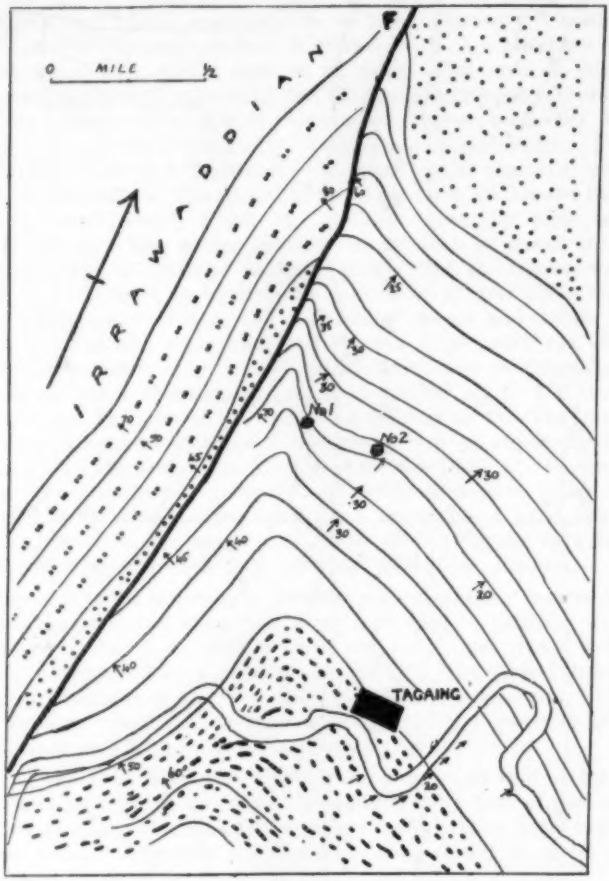

FIG. 16.
THE TAGAING STRUCTURE—A STEEPLY PITCHING "NOSE."

January, 1911, a well was put down by the B.O.C. at Uyin (6 miles north-east of Allanmyo) and reached 3500 feet, getting a little gas only.

(9) *Kanhla.*—The structure of this fold, lying in the midst of a large area of Peguan, is illustrated in the annexed diagram. The persistence of faith, hope and effort where oil is concerned in Burma may be gauged from the fact that the Union Oil Co.[21] tested this not very satisfactory structure as recently as 1921–4. The rig was a conspicuous object from the River Irrawaddy, which is here the chief highway of Burma, and even a small strike would have been a matter of no little amusement for the well lies within a stone's throw of the B.O.C. pipe line and one of the pumping stations.

(10) *Kyundaw Island.*—A curious nose-like structure passes through this island, and the B.O.C. commenced a test about 1909–10. In 1913 it was rumoured that a deep rotary test was to be attempted, but apparently nothing was done.

(11) *Tagaing.*—Tagaing belongs to the category of oilfields which are no more. The oil was obtained from the steeply pitching northern nose of a very extensive anticline. The structure was unpromising and had been previously condemned, but oil was struck by the Twinza Oil Company in 1916 (the bore having been commenced in May, 1914). The oil was apparently held up on a "terrace" caused by a change of pitch. A little oil was still being produced from three wells when the writer studied the area in 1922. In No. 1 well a little oil was obtained at 260 feet, but the main sand was at 2350. The following table gives the production of the area :—

	Gallons.		Gallons.
1914	22,836	1918	63,000
1915	25,920	1919	113,784
1916	35,000	1920	91,329
1917	30,000	1921	66,372

3. The Prome and Henzada Districts.

South of the Thayetmyo District lie the Prome and Henzada Districts. Paukkaung and the neighbouring parts of the Pegu Yoma are in the Prome District, but there are also structures in the heart of the Irrawaddy valley which have oil and gas shows and early attracted attention of the B.O.C. According to Pascoe the B.O.C. drilled the following wells, all prior to 1910 :—

(*a*) 200 yards south of Kayinzu ;
(*b*) At Namayan, where there is an oil seepage associated with a fault ;
(*c*) Near Thingan, close to a seepage which lies apparently in a syncline ;
(*d*) Near Taungbogyi, where four shafts had been sunk by a Chinese in 1871. Here the strata are Eocene in age.

4. Western Minbu.

The western part of the Minbu District is interesting from several points of view. Structurally the region is a continuation northwards of the Yenanma area, but the dips have increased to an average of 30° to 45°. The whole thickness of the Peguan is exposed; the harder sandy bands stand out as ridges, the softer shales have weathered into hollows. A rough section (Fig. 17) has

Fig. 17.

SECTION THROUGH WESTERN MINBU, ROUGHLY ALONG THE LINE MARKED A–B ON FIG. 18. THE CROSSES INDICATE SEEPAGES.

been appended to show the hopeless nature of the country for the retention of oil. Yet such was the effect of the Yenanma strike and the belief in seepages—many of the oil sands of Minbu must of course be represented among the outcropping beds—that when the writer studied the area in 1922 there was not a square mile which was not covered by prospecting licences. It has not yet been explained that the system of exploration adopted in Burma is in the first place to roughly investigate the ground and then to apply to the Government for a "prospecting licence" over any area which appears promising. The P.L. is granted for three years and may, in certain circumstances, be renewed for a further period. It gives the holder, in return for a nominal rent, the right to prospect for those minerals mentioned in the licence, and to carry out exploratory development. In the event of the licensee neglecting to carry out any development, the grant may be cancelled. During the three years a careful survey, trial borings, etc., can be made. Then, if the area is proved of value, a mining lease is taken out over the area required. Taking out a P.L. is the equivalent of staking a claim. Hence the rough map of Western Minbu showing areas held under prospecting licence in 1922 is of interest as showing the glamour of oil (Fig. 18).

The road to Western Minbu is the usual rough track, and passes the Rest Houses of Sittaung and Pyawbwe. Each visitor to the Rest House must sign the register and, unless he is a Government servant, pay a nominal fee for lodging. Much of interest is often to be gleaned from the old register. Thus we find a well-known geologist—at present exploring in West Africa—still owes the Government of Burma 8 annas for lodging at Pyawbwe; it also

reveals that Mr. Beeby Thompson paid a flying visit to Western Minbu on behalf of the Union Oil Company in the early part of 1922. But it will be very surprising if a field of any importance develops in this part of Minbu District.

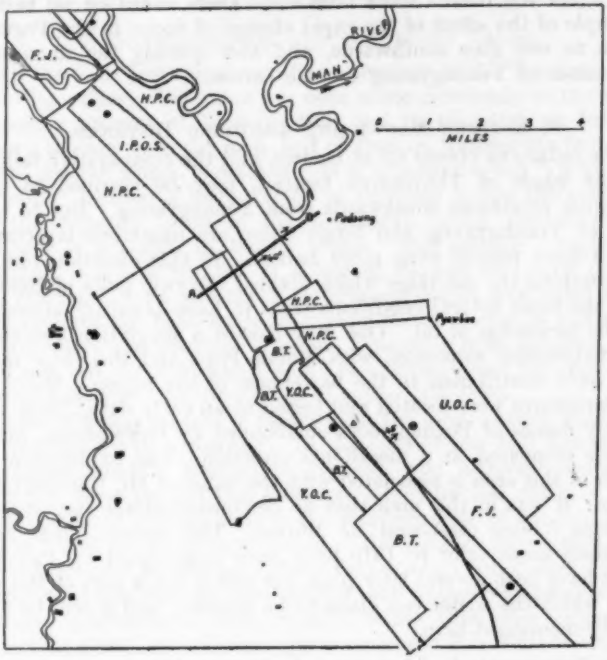

FIG. 18.

DIAGRAM SHOWING AREAS HELD UNDER PROSPECTING LICENCE IN WESTERN MINBU IN A REGION WITH OIL SEEPAGES, BUT WHERE A LARGE FIELD COULD SCARCELY EXIST. THIS IS CHARACTERISTIC OF ALL AREAS IN BURMA WHERE THERE IS EVEN A SIGN OF OIL. THE CROSSES SHOW SEEPAGES.

5. ONDWE.

Ondwe is one of the most instructive areas in Burma. It is a beautiful, open dome, lies about 25 miles south-south-east of Yenangyaung and about 20 miles east-north-east of the productive northern end of Minbu. The axis of the fold is almost on the same line as that of Yenangyaung. The dome was first found by Mr. Sethu Rama Rau, Sub-Assistant of the Geological

Survey of India.[22] From its structure and position there was every reason to believe that here was an oilfield which would rival Yenangyaung and Singu. The I.B.P. were the first in the field, but after years of effort they got nothing but a little gas. The area was given up, only to be taken on by another company; but again the results have been nil. There could be no better example of the effect of the rapid change of facies in the Peguan rocks as one goes southwards, and how quickly the numerous rich sands of Yenangyaung become barren.

6. Eastern Magwe and adjoining Districts.

The failure to obtain oil at Ondwe, and the comparative failure of the whole of Thayetmyo District, may be ascribed to the changing conditions southwards from Yenangyaung. But to the east of Yenangyaung and Singu there are numerous structures which have proved even more barren. In this direction one is approaching the old ridge which divided the twin gulfs of Burma and the more littoral conditions seem to have been unfavourable to the formation of oil. One may hazard a suggestion also that the vulcanicity associated with Mount Popa and this ridge may also have contributed to the barrenness of the region. Many of the structures were located and tested at an early date; they are mostly domes of Peguan rocks surrounded by Irrawaddian, more or less elongated in a meridional direction. The exploration of much of this area is associated with the name of Mr. Cunningham Craig; it was in this area that he demonstrated the importance of cross folding (east-west) in Burma. The various inliers and the tests made prior to 1910 have been enumerated by Pascoe; there have been several later tests, but this is not a part of Burma with which the writer can claim to be familiar, and it will be but briefly mentioned here.

(1) *Gwegyo.*—A long, narrow, faulted and twisted anticline, roughly parallel to the Singu fold and only about 8 miles to the east. The B.O.C. put down six wells in the northern (Payagyigon-Ngashandaung) area and got a little oil, but not in paying quantities. The B.O.C. also tested the northern area near Tetma.

(2) *The Pagan Hills.*—A similar structure, immediately to the north of the last, on a line two or three miles further east. The B.O.C. drilled two wells.

(3) *Kabat.*—Another anticline with the same general direction, 28 miles east of Singu but only 10 miles from the old volcano of Mount Popa. The B.O.C. drilled three wells and obtained quantities of gas.

(4) *Wèlaung.*—Another anticline six and a-half miles east-north-east of the last. The B.O.C. drilled one well.

(5) *Wetchok-Yedwet.*—This fold is of a different character, being a very open dome. The B.O.C. tested this structure with no results, and later tests have been made by other companies. The axis of the fold is 21 miles east-north-east of Yenangyaung.

7. Ngahlaingdwin and connected Areas.

All the folds just mentioned lie to the east of the Yenangyaung and Singu lines. Reference has been made previously to the wide gathering ground of Yenangyaung and to the west no fold is known to exist until the main belt of Peguan, forming the foothills of the Arakan Yoma, is reached. It is necessary to say "is known to exist," because a huge stretch of alluvium covers the country on the opposite banks of the Irrawaddy facing Yenangyaung. If there is a region in Burma where "wild-catting" might be justified, it is this region. If a fold of Peguan *does* exist under the alluvium, then another Yenangyaung might well exist also. One attempt has been made to explore this area, but it was both an expensive and abortive attempt. Speaking from memory, the well was put down by the Union Oil Company and the cost was said to have run into three lakhs of rupees (£25,000).

West of Singu no fold is found until the long, narrow anticline of Ngahlaingdwin is reached. In the core of this fold Pondaung Sandstone (middle Eocene) is exposed, and although seepages from the lower part of this sandstone occur further north, it was from the lower Peguan beds in the southern nose of the fold that it was hoped oil would be obtained. The Ngahlaingdwin area was the subject of a protracted dispute between the B.B.P. and I.B.P. Companies regarding the boundaries of their respectively prospecting licences. Government now usually insists that one corner or "starting point" of an area applied for under P.L. shall be clearly marked by an erection on the ground, but it has been commonly permitted for the area to be defined with reference to points marked on the one-inch Survey of India maps. The older maps are often far from accurate, hence the dispute. The B.B.P. came off somewhat the better in the dispute, but it has merely given them the benefit of spending the lion's share of the money in trial drilling—with no results of commercial value.

8. The Chindwin.

The problems of the Chindwin are in many ways quite different from those of central or southern Burma. Many of the horizons of the Peguan rocks have become continental in character and non-petroliferous, but there remains a sufficient thickness of

Peguan of the requisite character to give the fine little field of Indaw. But in the Chindwin area the belt of gently folded rocks of Peguan and Irrawaddian age is relatively narrow: the cliffs which in so many regions flank that most charming of rivers, the Chindwin, are of Eocene rocks. But here a new interest arises, for several horizons in the Eocene are petroliferous. It is fortunately not the purpose of this paper to attempt to catalogue the oil seepages and gas shows of Burma, for the list from the Chindwin Eocene alone would be a very long one. For the most part the Chindwin Eocenes are involved in long, narrow folds with roughly north and south axes. The dips on the flanks of these folds are often comparatively gentle, but towards the centre the beds may be vertical and even overfolded. Hand-dug wells in the centres of such folds often collect a few barrels of oil, but the conditions are rarely such as to encourage drilling. On the other hand, one remembers the steepness of the folding in the Assamese fields such as Digboi and an otherwise hopeless proposition appears to have some promise. The geology of a typical portion of this Eocene folded belt has been described by the writer.[23] To the east where the folds become gentler an added complication appears in the shape of unconformity. The domes of Medin, north-west of Kani, and of Palusawa afford good examples. Both of these lie to the south of the Shwebo Hills—the watershed which bounds the Chindwin valley to the east—whilst further south lie the Shinmadaung Hills. Along the latter it seems probable that the old floor of the Burmese Gulf approaches close to the surface, and the failure of a B.O.C. test here is not surprising. Still further south a faulted, southerly pitching anticline was tested by the I.B.P. near Kyaukwet.

Much of the Chindwin area has extensive evidence of vulcanicity, the volcanic rocks ranging in age from pre- or early Peguan (in the Shwebo Hills) to recent in the ash craters near the banks of the Chindwin above Monywa.

Broadly speaking, the only favourable structure in the post-Eocene area is that which forms the Indaw field. In the Eocene area the B.O.C. at an early date drilled two holes near the crest of a fold below the Mahodaung crest. But careful geological work by the I.B.P. showed that there was one area definitely domed, and a test well was initiated at Yagyi, about 16 miles west of Kani. The well was only down a few hundred feet when the writer visited the area on behalf of the Yomah Oil Company in February, 1922, but months and even years of bad luck followed —sickness in what is a notoriously unhealthy part of Burma, crooked holes and other troubles—and the work was eventually suspended.

VI. Summary and Conclusion.

1. The present communication is a natural complement to the writer's previous paper, on "The Conditions Governing the Occurrence of Oil in Burma," and by analysing the various existing fields and their production and by describing a large number of unsuccessful tests supplies the proofs to the theoretical conclusions drawn in the previous paper.

2. The Yenangyaung and Singu fields lie not only in the heart of Burma but also in the heart of the oil-lands of the country. There one finds not only conditions suitable for accumulation of oil in vast quantities, but geologically speaking conditions suitable for the formation of oil persisted for a relatively long time, and resulted in an extensive succession of oil sands. To the south deeper water sterile marine clays take the place of the oil measures and oil is restricted to certain sandy horizons. The rapidity of the change is shown by Ondwe, the general nature of the change is proved by the large number of unsuccessful test wells in the Thayetmyo, Prome and Henzada districts, many of which are described. On the other hand, to the north of Singu the oil measures pass into deposits which are predominantly continental (freshwater sands and clays), though even as far north as Indaw there may be rich accumulations in suitable structures. To the east and west of Yenangyaung the oil measures change in character, as one is approaching the shore lines of the old gulf. Promising structures to the east, such as Gwegyo and Yedwet, are barren, to the west suitable structures are few.

3. It is hoped that the present paper will finally kill the myth that there are vast unexplored areas of possible oil country. Several of the existing fields have good reserves and a long life, but there are small hopes of extensive new fields. Although the fortunes of the Indo-Burma Oilfields (1920), Ltd., have proved the hard fate which almost certainly awaits the newcomer, the point deserves emphasis.

4. It is hoped that this paper will have emphasised a matter which deserves emphasis. That is the tireless, careful and far-sighted exploratory work which the three great companies have carried out on behalf of their shareholders. The writer has no interest whatsoever in any of the companies in Burma—apart from having in the past been a servant of two of them—and therefore is at liberty to express the opinion that the oil industry in Burma is a very well run one.

DISCUSSION,

Mr. E. H. Cunningham-Craig, in opening the discussion, said that he had greatly enjoyed hearing the paper and seeing the illustrations that had been shown, particularly those showing ground which he personally mapped many years ago. His first acquaintance with Burmese oil was in little square bottles. It was then called "Rangoon oil," and he used it for cleaning the long Snider rifle which he carried in his School Corps. He well remembered remarking upon its wonderful green fluorescence —although he did not know that word in those days—and wondering why it was a reddish-brown colour by transmitted and green by reflected light. When many years afterwards he saw the oil being baled up in Burma he recognised it immediately as the unadulterated oil he had used in his school days. He first went to Burma a few months after leaving the little island of Trinidad where he had been studying oil in the field for the first time, the Trinidad oil being a very different oil from the Burmese oil. Burma was one of the greatest disappointments of his life, because he expected to find it hardly scratched from the point of view of oilfield development. It did not take him very long, however, to come to the conclusion that there was very little chance of finding big oilfields in Burma beyond those that had already been discovered, although they were not more than partly exploited. He desired to refer to the remarks the author had made in regard to the variation in strata between continental, fluviatile and marine. He commenced in April, 1908, to obtain from all available districts the percentage of clay and sand that was either exposed at the surface or given in the logs of wells. He could not get it very accurately from the logs of the wells, but a general idea was obtained from the amount of clay and sand whether the deltaic, the fluviatile, or the marine deposits were being approached, and it was soon very easy to find an ideal position in which the strata were not too much marine, too much deltaic, or too much fluviatile, and where the delta had remained stationary for a considerable time. At the end of two years it was quite easily possible to draw a line marking off the area that was likely to be productive, and the area from which a production of oil in quantity could not be expected, however good the structures were. The line drawn at that time had remained pretty well correct ever since, although in a certain number of fields chances had to be taken, where it was finally proved by the drill that there never had been any hope of producing oil in quantity. It was possible to dismiss the eastern part of the gulf very soon, because the lower Pegus were probably never deposited in it at

all, in fact some of it was land even in Irrawaddy times. It had been most interesting to him to see the oilfields of Burma, but he could not help thinking it was a pity that there was not a certain amount of pooling of information among all the companies, particularly the companies which came in at a little later stage, because so much of the ground that had been laboriously mapped and rejected was taken up years afterwards by one company or another and a great deal of money uselessly spent on development work. At the present time there was a good deal of pooling of information between different companies in Trinidad, and that had had a very good effect. He well remembered, while in Burma, that when he mentioned to those engaged in the oil industry there the possibilities of oil production in Trinidad, they were all inclined to laugh at him, but in a year or two he was able to inform them that there was more productive oil in the little island of Trinidad than in the whole of Burma, which was 1309 times as large. It was well known that at the present time there was more oil being produced in Trinidad than in the whole of Burma.

Major T. H. R. Garrett congratulated the author on his excellent paper, which he thought would prove of great value to the members. In the first place it brought up to date a great amount of information which was scattered about in various books and papers. In the second place he had laid stress on the point that structure-hunting was not everything, as all the members well knew, although he could not remember having seen the point so plainly set forth as it was in the present paper. Some of the photographs that he had been shown were of great interest to him, particularly those of Ngahlaingdwin, as he held the first prospecting licences over that piece of ground.

Dr. J. A. L. Henderson said that he had no practical knowledge of the geology of Burma, but he had been much impressed by the very positive nature of the author's condemnation of the oil possibilities in certain types of structure and of sedimentary variation illustrated by him. Experience in oil geology proved that it was necessary to be very careful in forming positive opinions on such subjects, owing to the necessarily incomplete evidence. The more one knew of geology, the more one realised the traps which existed which Nature did not always disclose. For instance, in certain structures which a geologist might legitimately condemn theoretically, on the available evidence, interruptions and variations might occur which nullified his conclusions.

Dr. Dudley Stamp, in reply, said that few points had been raised in the discussion which called for any lengthy reply. In reply to Dr. Henderson's remarks, he was sorry if in reading his

paper he had spoken in too positive a manner in condemning particular types of structures, because he had not intended to do so at all. He had hoped the paper would have brought out the great disadvantages and difficulties under which the geologist worked, in that it showed that some of the most promising structures in Burma, both on account of their character and situation, had been proved by the drill to be barren. An example of that was Ondwe. On the other hand, many structures which geologists might quite legitimately condemn had proved themselves to be oilfields of considerable value even at the present day, a very good example of that being the northern end of Minbu. He thought the geologist would have been justified in condemning that structure; nevertheless, it was a producing oilfield, although not a big one at the present time. He thought no condemnation could be levied against any geologist who expressed surprise at the richness of the southern blocks of the Singu structure, in the area worked by the B.B.P. It was a long way down the pitch, and, as he had stated in the paper, it was necessary to drill to 3000 feet before getting below the water and into the oil sands. He would be rather inclined to say that the geology of Burma illustrated beyond everything else the difficulties which might beset the geologist in saying "Yes" or "No" in regard to a particular structure. That was the real explanation of the exploration and continued drilling which was still going on even in areas which had been rejected. He desired to remind Mr. Cunningham-Craig that, in those areas which were ruled out by him as being of no value, were to be found Yenanma and Padaukbin, which while they had not been large enough as oilfields to be of value to the company which exploited them, were shallow fields which might have yielded a nice little return if they had been worked as a side-line by existing companies. His (the speaker's) advice to the Indo-Burma Petroleum Company to drill at Pyayè was, he thought, justified, and had such a gas field been struck elsewhere it would have been of considerable value. Yet this area also was in the tract unreservedly condemned by Mr. Cunningham-Craig and so also was the important field of Indaw. He hoped his condemnation of certain types of structure, to which reference had been made by Dr. Henderson, had not been stressed too much. As a matter of fact, it was rather the other way about. He thought the study of what had been learned in Burma called for the kind treatment of geologists.

The President said he was sure it would be the desire of the members to accord a most hearty vote of thanks to Dr. Dudley Stamp for his most interesting paper.

The resolution of thanks was carried by acclamation.

The President said that before closing the meeting he desired to announce that at a Meeting of Council that afternoon Major T. R. H. Garrett had been elected to fill a casual vacancy that had occurred on the Council.

The meeting then terminated.

REFERENCES.

[1] *Journ. Inst. Petr. Techn.*, 1927, **13**, 21-70.
[2] *Journ. Inst. Petr. Techn.*, 1928, **14**, 28-63.
[3] The first year of production by the Burmah Oil Company. The totals for the years 1888 to 1897 are estimated.
[4] An account of an Embassy to the Kingdom of Ava in 1795.
[5] Journal of a Residence in the Burmhan Empire.
[6] Journal of an Embassy to the Court of Ava in 1827. See also *Edinburgh New Phil. Jour.* (1827) and publications of the Geological Society, 1829–1834.
[7] Narrative of a Mission to the Court of Ava in 1855 by Captain Henry Yule (1858); Appendix by T. Oldham.
[8] *Memoirs of the Geological Survey of India*, 1912, **40**, Pt. I.
[9] The Indo-Burma Petroleum Co., Ltd., was formed on February 8, 1909, to acquire as a going concern the mineral oil business carried on by Messrs. A. S. Jamal Brothers and Company. The whole of the ordinary share capital was held by Messrs. Steel Bros. and Co., Ltd., and Messrs. Jamal Bros. and Co., Ltd., until the end of 1921, when the latter company disposed of its shares. Messrs. Steel Bros. now hold 69 per cent. of the ordinary capital. Until 1925 the I.B.P. had a large holding in the Attock Oil Co., Ltd. The dividends of the I.B.P. have been uniformly high—averaging 27 per cent. and ranging from 8¾ per cent. in 1911 to 75 per cent. in 1919.
[10] The B.B.P. was formed in 1910 to acquire a controlling interest (now 96 per cent.) in the Rangoon Oil Company and to purchase the Rangoon Refinery Company and Aungban Oil Company.
[11] Here the author, speaking from memory, is subject to correction.
[12] No accurate figures can be even suggested for Yenangyaung, but for the rate of accumulation of the Peguan sediments see Stamp, *Geol. Mag.*, **62**, 1925, pp. 515-26. By counting the individual laminæ of the banded sediments the duration of the Peguan has been calculated at 2-2½ million years.
[13] The oilfields of Yenangyaung-Singu, Yenangyat and Minbu were divided by Government into square-mile blocks and a detailed survey on the scale of 8 inches to the mile made of the area so demarcated.
[14] Actually folding of the Tertiaries commenced in early Eocene times and continued throughout. Thus Irrawaddian rocks rest uncomformably on Eocene at Myaing and Medin but Peguan rocks appear again further north.
[15] *Journ. Inst. Petr. Techn.*, 1925 (Oct.), Vol. 11, No. 52, pp. 481-485.
[16] It is suggested that the location of the B.O.C. wells was the result of the *two* separate sands shown in Fig. 10 being compared.
[17] Subsequent investigation shows that the inlier was indicated on a one-inch map of the Geological Survey of India, but on a sheet not officially published, according to the Superintendent-in-Charge of the Burma Party, 1923. Dr. Murray Stuart has recently informed the writer that it was he who noticed the inlier when on trek in December, 1909, and who was responsible for its indication on one of the maps available for public inspection at the Calcutta offices of the Geological Survey of India.
[18] From the Report of the Tariff Board regarding the grant of protection to the oil industry.
[19] Authority: Report of the Tariff Board.
[20] *Ibid.*
[21] A subsidiary of the London-Rangoon Trading Company.
[22] *Records of the Geological Survey of India*, **38**, 152.
[23] The geology of part of the Pondaung Range, Burma. *Trans. Mining Geol. Inst. of India*, 1922, **16**.

Alcohol Fuels for Use in Internal Combustion Engines.*

By J. G. King, Ph.D., A.R.T.C., F.I.C., and A. B. Manning, Ph.D., D.I.C.

I. Introduction.

In order to obtain the greatest efficiency from alcohol[1] in an internal-combustion engine, a much higher compression would be necessary than that for which existing engines are designed. By mixing it with other liquid fuels, a composite fuel is obtained that can be employed successfully in engines of present construction. Its miscibility with these other liquid fuels is therefore a matter of importance.

Modern liquid fuels are chiefly the petroleum spirits and benzol. Absolute alcohol is miscible in all proportions with petroleum spirits, but with industrial alcohol the miscibility will depend upon its water content and the temperature. The addition of benzol in suitable proportions to the alcohol-petrol mixture ensures a stable solution under all but extreme cases, and the combination of the three liquids should give a valuable fuel.

The experiments which follow have been designed to indicate the limiting factors in the preparation of such mixed fuels, and to show how these mixed fuels would behave in an ordinary standard petrol engine. A brief account of what has been done within the Empire and in other countries to produce alcohol for this purpose is contained in a paper on "Alcohol for Power Purposes," contributed by Sir F. L. Nathan to the 1928 Fuel Conference of the World Power Conference.

II. Fuels Used.

The fuels used in the experiments and their particulars are as follows:—

1. *Alcohol* (diluted to any required strength).

	By volume.	*By weight.*
Alcohol	95·0	92·4
Water	5·0	7·6

Specific gravity 15/15° C., 0·816.

* Paper received April 16th, 1929.

[1] The word *alcohol* will signify ethyl alcohol and its strength will be quoted by volume unless otherwise specified.

Name of refined spirit.	Source of crude oil.	Specific gravity 15/15° C.	First drop.	60° C.	70° C.
B.P. Spirit No. 1 (1920) ..	U.S.A.	0·723	45° C.	1·0	4·6
Imperial naphtha	Mexico	0·726	55° C.	0·4	1·2
Refined spirit	Persia	0·714	41° C.	2·0	10·5
Refined benzine	Persia	0·732	45° C.	0·5	3·9
B.S.R. benzine	Dutch Borneo	0·783	58° C.	—	0·3
Miri benzine	Sarawak	0·772	78° C.	—	—
Shell spirit	—	0 730	43° C.	0·5	3·0
B.P. spirit (1927)	U.S.A.	0·743	45° C.	2·0	4·0

TABLE I.

Petroleum spirits from different sources.

of l.	Specific gravity 15/15° C.	Distillate p						
		First drop.	60° C.	70° C.	80° C.	90° C.	100° C.	110
	0·723	45° C.	1·0	4·6	13·4	26·1	40·4	54
	0·726	55° C.	0·4	1·2	4·7	13·9	25·0	35
	0·714	41° C.	2·0	10·5	26·5	44·9	61·0	74
	0·732	45° C.	0·5	3·9	10·2	20·0	31·3	43
	0·783	58° C.	—	0·3	1·1	4·0	14·9	35
k	0·772	78° C.	—	—	—	0·6	7·2	27
	0 730	43° C.	0·5	3·0	8·2	19·9	32·5	47
.	0·743	45° C.	2·0	4·0	15·0	26·0	39·0	52

fferent sources.

Distillate per cent. by volume.

C.	100° C.	110° C.	120° C.	130° C.	140° C.	150° C.	160° C.	170° C.	Final B. Pt. °C.
·1	40·4	54·8	66·2	75·3	81·8	87·3	91·1	94·1	197
·9	25·0	35·8	48·6	62·0	72·6	82·0	89·0	93·1	190
·9	61·0	74·0	83·2	89·0	92·3	94·4	96·5	—	165
·0	31·3	43·7	54·2	65·7	74·0	81·0	86·4	90·5	195
0	14·9	35·1	53·4	68·3	81·2	91·0	94·3	97·8	170
6	7·2	27·9	49·1	65·0	75·8	83·8	89·3	93·4	195
9	32·5	47·0	57·2	68·0	76·1	83·1	87·5	91·0	195
·0	39·0	52·5	62·5	71·0	78·0	84·5	89·5	93·0	190

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2. *Power Methylated Spirits.*[2]

	Composition by volume.
Alcohol (Alcohol 87·4, Water 4·6)	92·0
Benzol (N. B. Co., Ltd.)	5·0
Methyl Alcohol	2·5
Pyridine	0·5

Specific gravity 15/15° C., 0·802.

3. *Benzene* (commercially pure), 99·5 per cent.

Specific gravity 15/15° C.; 0·882.

4. *Power Benzol* (N. B. Co., Ltd.).

	Composition.	*Distillation.*	
Benzene	74·8	82° C.	First drop.
Toluene	22·3	to 90° C.	63·0
Paraffins	2·6	to 100° C.	88·1
Carbon Disulphide	0·2	to 110° C.	97·0
		to 111·5° C.	100·0

Specific gravity 15/15° C., 0·879.

Freezing range : —11° C. first crystals ; —18° C. almost completely solid.

5. *Shell Motor Spirit.* See Table I.

6. *B. P. No.* 1 *Spirit.* See Table I.

7. *Petroleum Spirits.* See Table I.

The five spirits, the distillation ranges of which compared with Shell Motor Spirit and B. P. No. 1 Spirit are given in Table I., cover a world range with the exception of Russia, from which no sample was obtainable at the time of the experiments.

8. *Spirits for the Low Temperature Distillation of Coal.*—These spirits were obtained by the carbonisation at 600° C. of bituminous coal of medium caking power. The plant used was that discussed in the Report of the Fuel Research Board, 1920-21, Section " Low Temperature Carbonisation."

One spirit was obtained by distillation of the tar, the other by oil washing of the gas. Both were rich in unsaturated compounds, and had a tendency to polymerise even after careful refining with sulphuric acid and caustic soda.

	Tar spirit.	*Gas spirit.*
Specific gravity at 15/15° C.	0·82	0·73
Yield of refined spirit per ton of coal. Gals. ..	1·20	1·39

[2] See Statutory Rules and Orders, 1921, No. 1318. Power Methylated Spirits.

The distillation ranges are shown graphically in Figure 1, in comparison with Shell Spirit and B. P. No. 1 Spirit.

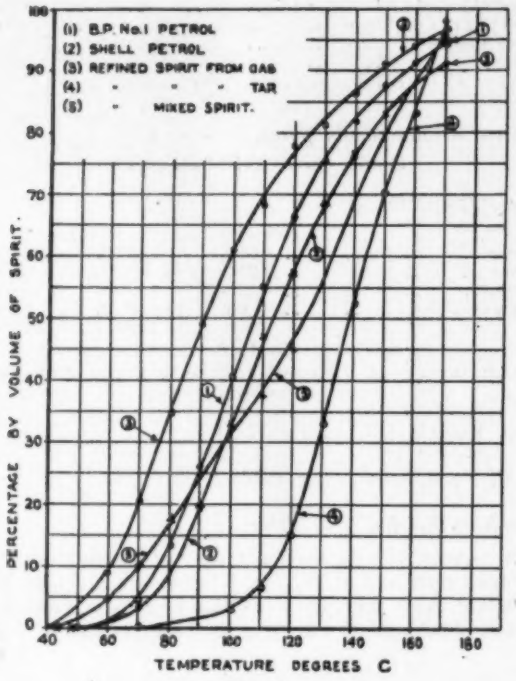


FIG. 1.

DISTILLATION RANGES OF REFINED SPIRIT FROM LOW TEMPERATURE GAS AND TAR IN COMPARISON WITH THAT OF PETROL.

III. EXPERIMENTAL.

The experimental work may be divided into two sections, involving a slight difference in procedure. This was due in part to an unavoidable lapse of time between the two series of experiments.

1. *Determination of Critical Points.*—In the first series of experiments the volumes of the ingredients were generally varied so that the total volume of the mixture amounted to 10 c.c. The ingredients were each measured in a standardised burette kept

at 15° C., and the requisite quantities were run carefully into thin glass test tubes. The tubes were then immersed in a thermostat at the required temperature, and allowed to stand until that temperature had been attained in the test mixtures. With suitable agitation of the thermostat this point was generally attained in about 15 minutes, and the observations were taken after a further 15 minutes had elapsed. At first it was necessary to determine the critical point approximately, and then to make up a second series of mixtures to fix the point more accurately. Later, however, as the collection of data went on, it became possible to dispense with the first, or prospecting, set of mixtures. In a definite series, also, it was possible to reduce the number of experiments necessary by plotting the data immediately and following the resulting curves for approximate values.

The critical point selected was that at which separation did not take place of any constituent of the mixture. The first indication of such separation was the appearance of opalescence which increased until a definite separation of the mixture into layers was obtained. The proportions in the mixture which just failed to show opalescence were taken as the critical proportions for that temperature.

In triple mixtures a selected quantity of one ingredient was measured out and the other two ingredients added, the sum of the two being always equal to 10 minus the first. The step between successive mixtures was 0·05 c.c., so that the error in the value taken was of the order of 0·25 per cent. (average) on the "safe" side. In the tabulated data below the results are all quoted to 0·5 in 100 c.c. of the mixture, but it should be remembered that the amount of the ingredient, whose limiting quantity is being determined, is below the true critical quantity by an amount equal to, at most 0·5, and on the average to 0·25.

The accuracy of determination of temperature was well within this error. Two standardised thermometers were used, one in the thermostat and one in a blank tube containing 10 c.c. of the liquids under investigation. The cooling bath was kept constant within 0·05° C., and the final examination of the tubes was made 15 minutes after the temperature in the blank tube equalled that in the bath.

In the second series of experiments, phase diagrams for the three component system petrol-benzene-alcohol were constructed for temperatures from +20° C. to −10° C. and for 94 to 98 per cent. alcohol. Strictly speaking, these are four component systems, but as the question at issue is rather the determination of their miscibility ranges than the composition of the phases in the non-miscible region, the results are conveniently recorded on a three-component diagram.

In this series of experiments critical points were determined as follows: To a known volume, usually 10 c.c., of one component, or a mixture of two components in a test tube in the thermostat, a third component was added slowly from a burette, keeping the mixture well stirred, until the critical point (*cf.*, p. 352) was reached. This point being known approximately from preliminary experiments and general considerations, the liquid from the burette was run in a drop at a time at 5 minute intervals when approaching the end point.

For triple mixtures critical points were obtained in two ways, and there was good agreement between the two sets of points:—

(1) Petrol was added to various benzene-alcohol mixtures until mixtures just failed to show opalescence.

(2) Alcohol was added to mixtures of petrol and benzene and two points were obtained, the first being where separation just failed, and the second when the mixture finally cleared.

The accuracy of the determination, except at −10° C., was well within 1 per cent. and the temperature regulation was also quite accurate, two standard thermometers being kept, one in the bath and one in a blank tube containing 10 c.c. of the liquids under investigation.

2. *Results of First Series of Experiments.*—(a) *Binary Mixtures,* (i.) *Of Alcohol and Petrols.*—The ranges of miscibility at 15° C. of 95 per cent. alcohol with petrol (No. 4, Table I.) extend from 0 per cent. to 1·1 per cent. and from 63·5 per cent. to 100 per cent. of alcohol by volume. The lower range is so limited as to be outside the scope of the present investigation.

Absolute or 98·6 per cent. alcohol, on the other hand, is miscible in all proportions with petrol. On the addition of water to the mixture petrol separates until at a certain concentration none remains in solution:—

Addition of water to 20 c.c. of a mixture of equal proportions of absolute alcohol and petrol (No. 4).
Temperature 0° C.

Water.	*Mixture.*	*Alcohol solution.*	*Petrol.*
c.c.	c.c.	c.c.	c.c.
0·3	20·3	—	—
0·35	20·3	16·5	3·8
0·6	20·4	13·5	6·9
1·0	20·6	12·2	8·4
1·5	21·0	12·0	9·0
2·0	21·4	12·1	9·3
2·5	21·9	12·4	9·5
3·0	22·3	12·7	9·6
3·5	22·8	13·0	9·8
5·0	24·3	14·5	9·8

In this table the addition of 0·6 c.c. corresponds to the formation of 95 per cent. alcohol (10·5 c.c.).

At 20° C. a similar set of figures was obtained; 0·45 c.c. of water were sufficient to start separation into two layers.

The practical use of petrol—absolute alcohol mixtures is therefore limited by the precautions necessary to prevent admixture with water. Although stable in any proportions when water-free, the addition of even so small a quantity as 1·8 per cent. of water is sufficient to cause marked separation. In a solution of equal parts of petrol and absolute alcohol the amount of the separated layer is as much at 0° C. as 36 per cent. of the volume of petrol present.

The miscibility of other petroleum spirits with 95 per cent. alcohol varies over a fairly wide range.

The miscibility limits for the six petroleum spirits described on page 350 and in Table I. are given below over a temperature range from 15° to −10° C. They are expressed in Table II. as volumes of petroleum spirit per 100 volumes of 95 per cent. alcohol, and in Table III. as the maximum percentages of petroleum spirit possible in homogeneous mixtures.

TABLE II.

Miscibility limits of certain petroleum spirits with 95 per cent. alcohol.

(Vols. per 100 vols. of alcohol.)

Petroleum spirit.	Source.	Limiting vols. of petrol per 100 vols. alcohol.		
		15° C.	0° C.	−10° C.
1. B. P. No. 1	U.S.A.	59	39	35
2. Imp. Naphtha	Mexico	46	33	28
3. Ref. Spirit	Persia	83	58	45
4. Ref. Benzine	Persia	57	41	34
5. B. S. R. Benzine	Dutch Borneo	263	114	70
6. Miri Benzine	Sarawak	56	38	32
7. Shell	—	52	36	30

TABLE III.

Limiting percentages of petroleum spirits in stable mixtures with 95 per cent. alcohol.

(Vols. per 100 vols. of solution.)

Petroleum spirit.	Limiting percentage of petrol in mixture (by volume).		
	15° C.	0° C.	−10° C.
B. P. No. 1	37	28	26
Imp. Naphtha	31·5	25	22
Ref. Spirit	45·5	36·5	31
Ref. Benzine	36·5	39	25·5
B. S. R. Benzine	72·5	53·5	41
Miri Benzine	36	27·5	24
Shell	34	26·5	23

The conclusions which may be drawn from these data are, that whilst certain petroleum spirits are fairly readily soluble (40 per cent.) at −10° C., others are soluble only to the extent of about 22 per cent. Reference to Figure 2 shows that B.S.R. benzine, and in a lesser degree Persian spirit, differ from the others in having higher solubilities. Their solubility curves are, however, steeper, and it is indicated that the range of solubilities is less at −15° C. than at 0° C.; 21 to 35 per cent. as against 25 to 53·5 per cent.

Ormandy and Craven[3] quote similar figures for five petroleum spirits. The figures in the following table are calculated from their Figure 4:—

TABLE IV.

Origin of spirit.		Specific gravity 15/15.	Limiting petrol per cent. in mixture with 95 per cent. alcohol.		
			15° C.	0° C.	−10° C.
Borneo or Sumatra ..	(A)	0·782	77	47	37
	(B)	0·723	70	43	36
American	(E)	0·719	42	31	26
	(F)	0·704	38	28	24
Miri Borneo	(H)	0·767	32	25	22

The range of solubilities with these petroleum spirits is given as grammes of hydrocarbon spirit per 100 gm. of solution. On a volume basis the difference in the figures would be small (1 to 2 units), so that the data are seen to be of the same order.

Erckman[4] has shown that at −10° C. the following are the solubilities of certain hydrocarbons in 95 and 90 per cent. alcohol:—

	Heptane.	Methyl cyclohexane.
Alcohol 95 per cent. ..	0 — 16 per cent.	0 — 27 per cent.
„ 90 „ „ ..	0 — 10 „ „	0 — 13 „ „

These figures throw light on the varying solubilities of the petrols examined in that the polymethylene hydrocarbons are definitely more soluble than corresponding members of the aliphatic series. The marked effect of reduction of alcohol strength is also apparent. This is a point of strong practical interest as the accidental addition of a small amount of water to a mixture near the stable limit would result in the separation of the solution into two layers.

(ii.) *Alcohol and Benzene.*—Absolute alcohol and benzene are miscible in all proportions at temperatures above the melting

[3] W. R. Ormandy and E. C. Craven, "The Physical Properties of Motor Fuels," Proc. Inst. Auto. Engrs., 1921–1922, **16**, 143.
[4] Phy. Chem. Res. on Liq. Fuels, *Chimie et Ind.*, 1920, **3**, 761.

point of the latter. The melting point of pure benzene is 5·4° C., and the initial freezing point of 90's benzol (National Benzole Company) is −11° C. Mixtures with alcohol are therefore normally susceptible to crystallisation only when pure benzene is used. The absolute alcohol-benzene mixtures which have initial crystallising points of 0° C. and −10° C. contain respectively 25·1 and 59·0 per cent. of alcohol. At a temperature of −10° C., therefore, the maximum amount of benzene permissible in a stable solution is 41 per cent.; of benzol the proportion would be much greater.

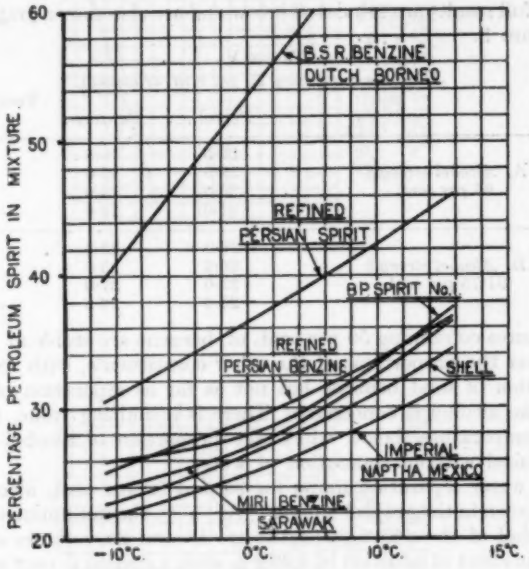


FIG. 2.

SOLUBILITY OF PETROLEUM SPIRITS IN 95 PER CENT. ALCOHOL.

All probable commercial mixtures of alcohol and benzol will therefore be stable to temperatures well below −15° C.

(*b*) *Ternary mixtures.*—In the examination of ternary mixtures it was decided to determine the limits of stability for mixtures containing respectively 50 per cent. by volume of alcohol, benzene and petrol. In this series the petrol used was B. P. No. 1 Spirit only (No. 1, Table I.).

(i.) *Alcohol Petrol and Benzol.*—Starting with 95 per cent. alcohol, and adding benzene and petrol in varying proportions, it was obvious that the limiting amounts of petrol would vary with temperature. In 100 volumes of the mixture containing 50 volumes of alcohol the limiting amount of petrol was 39·5 volumes at 15° C. and 31 volumes at –5° C. The effect of water can be gauged from corresponding values for 91·75 per cent. alcohol, a strength which corresponds to the addition of 2 per cent. of water to the mixed solvents. In this case the limiting volumes of petrol were considerably lower, 28·0 at 15° C. and 21·5 at –5° C.

The full results are tabulated below and are also shown graphically in Figure 3.

TABLE V.

Mixtures containing 50 per cent. of alcohol.

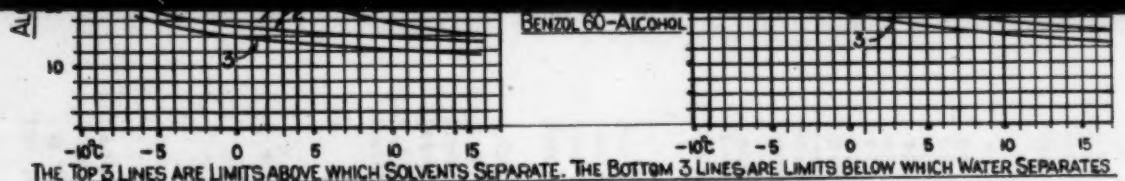
	Petrol.	Benzene.	Temperature ° C.
A. *Alcohol strength 95 per cent.*	39·5	10·5	15
	38·0	12·0	10
	36·0	14·0	0
	31·0	19·0	—5
B. *Alcohol strength 91·75 per cent.*	28·0	22·0	15
	26·5	23·5	10
	23·0	27·0	0
	21·5	28·5	—5

Mixtures containing 50 per cent. of benzene are stable at –5° C., whatever the proportions of the other constituents, with regard to separation of solid benzene but not as far as separation of water from the alcohol is concerned. There is a limiting value, varying with temperature, below which the proportion of alcohol cannot be reduced without separation of water.

The water separation limits for 95 and 92 per cent. alcohol are both shown in the graph Figure 4. At –5° C. the minimum amounts of alcohol of the above strengths are 18 and 29 volumes showing that the effect of addition of water in such a system is very marked.

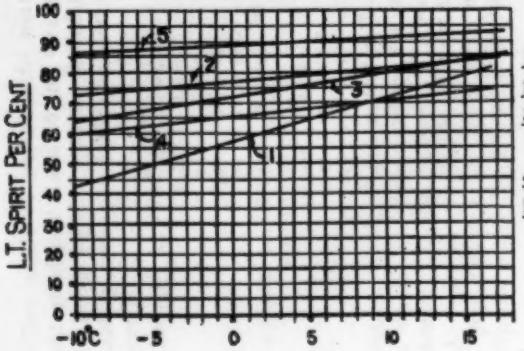
When mixtures containing 50 per cent. of petrol were considered it was found that, with this particular spirit no clear solution was obtainable at 0° C., the mixtures being either not miscible or showing water separation. Exploration at higher temperatures gave a graph, Figure 5, which indicated that the critical point was at about +3° C. With more dilute alcohol (92 per cent.) no clear solutions were obtainable even at 15° C. It is evident, therefore, that in a ternary mixture it is not practicable to have so high a percentage of petrol as 50.

In view of this limiting factor for petrol further explorations were made to determine the maximum amount which would yield



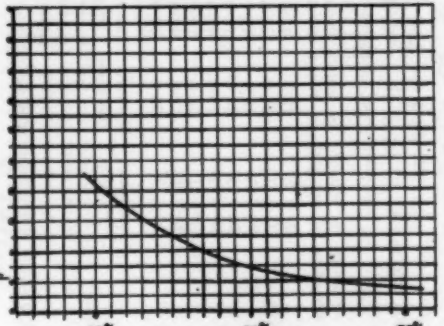
THE TOP 3 LINES ARE LIMITS ABOVE WHICH SOLVENTS SEPARATE. THE BOTTOM 3 LINES ARE LIMITS BELOW WHICH WATER SEPARATES

FIG.7. MISCIBILITY OF L.T. SPIRITS WITH 95% ALCOHOL

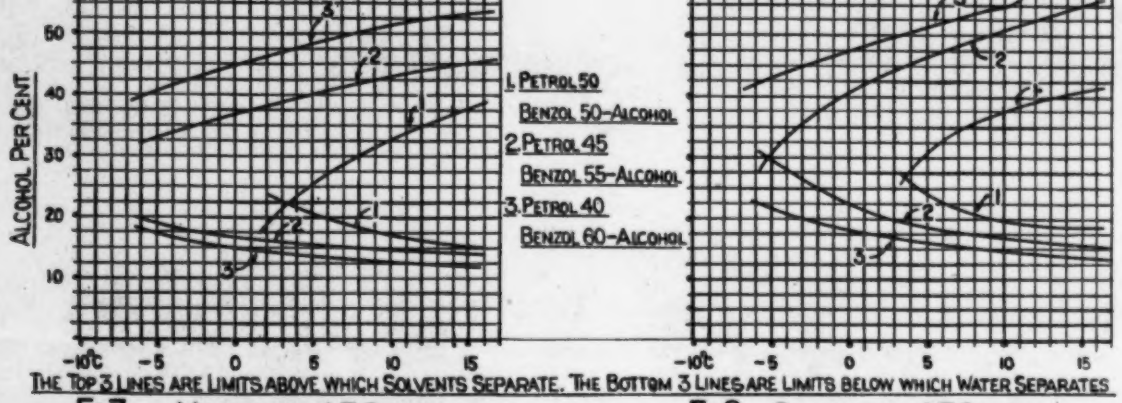


1. GAS SPIRIT
2. TAR SPIRIT
3. 55/50 MIXED SPIRIT
4. POWER BENZOL
5. MIXED SPIRIT WITH 50/50 ALCOHOL BENZOL

FIG.8. SOLUBILITY OF L.T. SPIRIT IN ALCOHOL OF DIFFERENT STRENGTHS



STRENGTH OF ALCOHOL



THE TOP 3 LINES ARE LIMITS ABOVE WHICH SOLVENTS SEPARATE. THE BOTTOM 3 LINES ARE LIMITS BELOW WHICH WATER SEPARATES

FIG.7 MISCIBILITY OF L.T. SPIRITS WITH 95% ALCOHOL

FIG.8. SOLUBILITY OF L.T. SPIRIT IN ALCOHOL OF DIFFERENT STRENGTHS

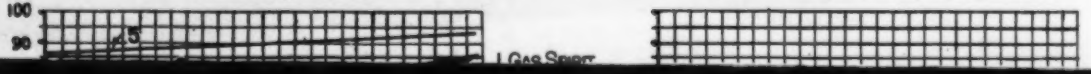


FIG.3. ALCOHOL = 50% OF MIXTURE
BENZOL = 50 – PETROL
①95% ALCOHOL. ②91·8% ALCOHOL

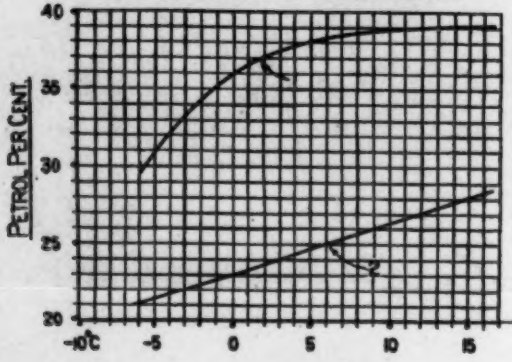


FIG.4. BENZOL = 50% OF MIXTURE
ALCOHOL = 50 – PETROL
①95% ALCOHOL ②92% ALCOHOL

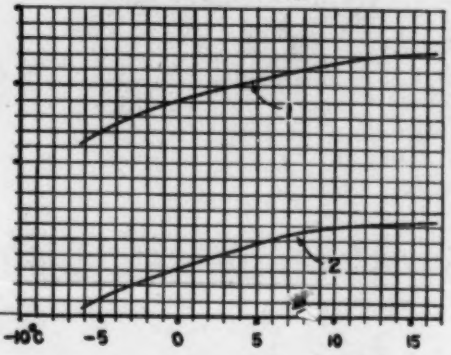


FIG.5. MISCIBILITY OF 95% ALCOHOL WITH B.P. No.1 SPIRIT AND BENZOL

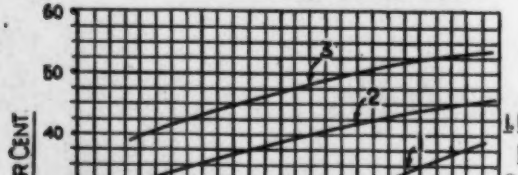
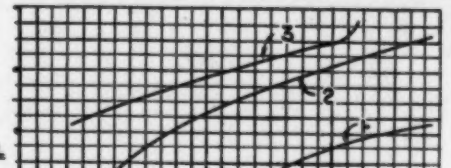


FIG.6. MISCIBILITY OF POWER METH. SPIRIT WITH B.P. No.1 PETROL & POWER BENZOL



stable mixtures. Two series of experiments were carried out in which the percentage of petrol was 45 and 40 respectively, the alcohol and benzene being together equal to 55 and 60 per cent.

Both limits of stability were again determined and are also shown graphically in Figure 5.

The limits of miscibility at −5° C. are therefore :—

Petrol.	*Alcohol.*	*Benzene.*
50	—	—
45	19 to 33	36 to 22
40	17 to 40·5	43 to 19·5

If these values are expressed per 100 parts of petrol the comparison is perhaps clearer.

	Petrol.	*Alcohol.*	*Benzene.*
45 per cent. petrol	100	42 to 73·5	80 to 49
40 „ „ „	100	45 to 100	108 to 49

(ii.) *Power Methylated Spirit, Petrol and Benzol.*—Experiments were continued in which the pure benzene was replaced by a commercial 90's benzol and the alcohol by power methylated spirit. In order to compare miscibility values with those using pure alcohol and pure benzene the limits were determined at 0° C. using one particular petrol, the British Petroleum Company's B. P. No. 1 spirit.

The percentage of power spirit necessary for complete mixing was first determined for a fixed percentage of petrol using pure alcohol and pure benzene. Similar points were then determined for pure alcohol and 90's benzol and for the power spirit and 90's benzol. The comparative points are given in Table VI. :—

TABLE VI.

Limits of miscibility of benzene and alcohol with B. P. No. 1 spirit at 0°.

Quality of alcohol and benzene used.	Mixtures containing 45 per cent. petrol.		Mixtures containing 40 per cent. petrol.	
	Alcohol per cent.	Benzene per cent.	Alcohol per cent.	Benzene per cent.
Pure alcohol and pure benzene	16·0 (1)	39·0	14·5 (1)	45·5
	39·5 (2)	15·5	48·0 (2)	12·0
Pure alcohol and 90's benzol	18·0 (1)	37·0	15·5 (1)	44·5
	39·0 (2)	16·0	47·0 (2)	13·0
Power methylated spirit and pure benzene ..	19·0 (1)	36·0	17·5 (1)	42·5
	39·0 (2)	16·0	47·5 (2)	12·5
Power methylated spirit and 90's benzol	22·5 (1)	32·5	18·0 (1)	42·0
	36·0 (2)	19·0	47·0 (2)	13·0

(1) Minimum amounts of alcohol or spirit necessary.
(2) Maximum amounts of alcohol or spirit necessary.

The range of miscibility of alcohol and benzene in a mixture containing 40 per cent. of petrol at 0° C. is therefore reduced by replacing pure benzene with 90's benzol from 33·5 (14·5 to 48) to 31·5 (15·5 to 47). With power methylated spirit in place of pure

alcohol the range is reduced from 33·5 to 30 (17·5 to 47·5) and with power methylated spirit and 90's benzol to 29·0 (18 to 47).

This reduction is confirmed in mixtures containing 45 per cent. of petrol, where the differences are more marked. It is therefore evident that the limits of safety of mixed motor fuel would be narrowed by the use of less pure alcohols.

In order to confirm this conclusion repeat experiments were carried out also at 0° C. with B. P. No. 1 spirit, power methylated spirit and, in turn, 90's benzol, a mixture of pure benzene and toluene in the proportion of 75/25 and finally pure toluene. The results are given in Table VII:—

TABLE VII.

Miscibilities at 0° C.

B. P. No. 1 spirit = 40 per cent. by volume.

Type of benzol.	Power methylated spirit.		Benzene or mixture.	
	Max.	Min.	Max.	Min.
Pure benzene	48	16·5	12	43·5
90's benzol	47	18	13	42
75/25 benzene-toluene	45·5	18·5	14·5	41·5
Pure toluene	41	26·5	19	33·5

The lower limits rise and the upper limits decrease steadily in the order shown, so that the range of miscibility decreases from 31·5 with pure benzene to 15·5 with pure toluene. This decrease with toluene obviously explains the action of the 90's benzol as it contains 22 per cent. of toluene.

The above conclusion holds for temperatures above those of the separation of the solid phase. Where triple points are considered the presence of toluene is an advantage. Ormandy and Craven (Proc. Inst. Auto. Engrs., 1921-1922, **16**, 143) have examined the solubility curves in 95 per cent. alcohol of benzene, toluene and xylene. Benzene, whose freezing point they quote as 5·2° C. shows a triple point at 2·7° C. when the solution contains about 88 per cent. benzene by weight. At 0° C. this solubility is reduced to about 60 per cent., and at −10° C. to about 30 per cent. With toluene, whose freezing point is as low as −95° C., the solubility at −30° C. is about 78. This difference so affects benzol containing 25 per cent. of toluene that the triple point is reduced to −11·5° C. at 85 per cent. solubility, while at −20° C. the solubility is still over 35 per cent.

Where a motor spirit is likely to be exposed to low temperatures, as in aviation, it would therefore be of advantage to use 90's benzol rather than pure benzene, so far as freezing out is concerned, but it would be necessary to remember that the range of miscibility is also reduced as shown in Table VII.

The miscibilities of the petroleum spirits available were then determined with power methylated spirits and 90's benzol. The results are given in Table VIII. and shown graphically in Figure VI. for B. P. No. 1 spirit only.

TABLE VIII.

Limits of miscibility at 0° C. of power methylated spirit and 90's benzol in different petroleum spirits.

Name of petrol.	Power methylated spirit per cent. possible at 0° C. Max.	Min.	Range.	Remarks.
(A) 45 *per cent. petrol.*				
B.P. No. 1 Spirit U.S.A.	36·0	22·5	13·5	*Excl. Imp. Naphtha.*
Imperial naphtha 0° C.	—	—	Nil.	Max. of points of water sepn. .. = 25·0
Mexico 1° C.	30·0	28·0	2·0	Min. of points of solvent sepn. = 33·0
Persian ref. spirit ..	45·5	18·0	27·5	
,, ,, benzine ..	38·0	21·5	16·5	Therefore nett range.. .. = 8·0
B.S.R. benzine Dutch Borneo	55·0	17·0	38·0	
Miri benzine Sarawak	33·0	25·0	8·0	
Shell spirit	35·5	23·0	12·5	
(B) 40 *per cent. petrol.*				
B.P. No. 1 spirit U.S.A. ..	47·0	18·0	29·0	Max. of points of water sepn. .. = 20·0
Imperial naphtha .. Mexico	42·0	20·0	22·0	Min. of points of solvent sepn. = 42·0
Persian ref. spirit ..	55·5	17·0	38·5	Therefore nett range.. .. = 22·0
,, ,, benzine ..	47·5	18·5	29·0	
B.S.R. benzine Dutch Borneo..	60·0	16·5	43·5	
Miri benzine Sarawak..	45·5	19·5	26·0	
Shell spirit	54·5	18·5	36·0	

The wide differences which are shown by the petroleum spirits investigated show that a wider research than the present would be necessary to cover the whole of the ground.

In the making of trade mixtures it is, however, indicated that the percentage of petrol will be limited to less than 45, as, for example, the Imperial naphtha from Mexican crude oil has no margin of safety at 0° C. and the Sarawak spirit very little. Stable mixtures (at 0° C.) containing 40 per cent. of petrol are possible with any of the petroleum spirits examined if the percentage of power methylated spirit lies between 20 and 42.

It is noteworthy that in the case of Dutch Borneo spirit there is no upper limit for alcohol, the 40 parts of petrol being miscible at 0° C. with 60 parts of power methylated spirit.

(*c*) *Low Temperature Carbonisation Spirits.*—The composition of motor spirits recoverable from the carbonisation of bituminous coal at "low" temperatures (about 600° C.) may vary considerably. The spirits examined below were obtained from the carbonisation of a South African bituminous coal in mild steel experimental retorts at the Fuel Research Station (Report of F.R.B., 1920–21, Second Section). From the gas, the yield of refined spirit was

1·5 gallons, and from the tar 1·2 gallons per ton of dry coal containing 8 per cent. of ash.

Both spirits were miscible in any proportion with benzene at temperatures above the freezing point of the latter. Their own freezing points were both below —50° C.

The miscibility of each spirit with alcohol was determined down to a temperature of —10° C.

Gas spirit, specific gravity 15° C. 0·731.
Tar " " " 15° C. 0·814.

Miscibility with 95 per cent. alcohol.

	Temp ° C.	Minimum alcohol percentage.	100 vols. alcohol can take up spirit equal to
Gas spirit	15	21·0	376 vols.
	10	28·6	250 "
	0	43·0	132 "
	- 10	57·4	74·2 "
Tar spirit	15	16·6	502 "
	0	23·0	335 "
	- 10	28·0	257 "
50/50 mixture	15	17·0	488 "
	0	28·6	249 "
	- 10	36·2	176 "

These results are also shown graphically in Figure 7, curves 1, 2 and 3. The gas spirit is distinctly less soluble than the tar spirit. The safe mixture of the blended spirit with alcohol contains not less than 36·2 parts of the alcohol.

The effect of dilution of the alcohol is again important and even a slight reduction in the strength of the alcohol has a marked effect on the solubility of the spirit. The following figures were determined at —10° C. for the gas spirit only :—

Alcohol strength volume per cent.	Minimum alcohol per cent. in mixture.	Spirit soluble in 100 vols. alcohol.
95·0 ..	57·4 ..	74·2
90·0 ..	86·0 ..	16·3
85·0 ..	93·4 ..	7·1

A reduction in the strength of the alcohol from 95 to 90 has therefore the very marked effect of reducing the solubility of the spirit in it from 74·2 to 16·3. These results are shown graphically in Figure 9.

In order that a mixed motor spirit should be " safe " at —10° C. therefore at least 36·2 per cent. of 95 per cent. alcohol must be present. If, however, a reasonable factor of safety is wanted against addition of water the alcohol percentage should be increased to 50.

The addition of benzene as an ingredient of mixed fuel reduces the amount of alcohol necessary for stability. The following stable mixtures were determined by adding spirit to a 50/50 mixture of 95 per cent. alcohol and benzene.

Gas spirit with 95 per cent. alcohol and benzene.

Temp. °C.	Gas spirit, per cent.	Alcohol per cent.	Benzene, per cent.
+15 ..	71·4 ..	14·3 ..	14·3
0 ..	62·2 ..	18·9 ..	18·9
−10 ..	56·6 ..	21·7 ..	21·7
	Mixed spirit.		
+15 ..	73·0 ..	13·5 ..	13·5
0 ..	65·0 ..	17·5 ..	17·5
−10 ..	60·0 ..	20·0 ..	20·0

These values are expressed graphically in Figure 7, curves 3 and 4.

(3) *Second Series of Experiments.*—The phase diagrams for petrol-benzene-alcohol mixtures are drawn in Figures 10 to 19. The components were (A) B.P. motor spirit, D^{20}_4 0·736, supplied 1927, (B) pure benzene, and (C) 94, 95, 96 and 98 per cent. alcohol respectively. To illustrate the method and to show the accuracy obtainable the results obtained at 10° C. with 95 per cent. alcohol are tabulated in full in Table IX., and plotted on the diagram of Figure 9.

TABLE IX.

Limits of miscibility at +10° C. for the system 95 per cent. alcohol-petrol-benzene.

Addition of 95 per cent. alcohol to petrol-benzene mixtures.			Addition of petrol to alcohol-benzene mixtures.	
Per cent. petrol in initial mixture.	Critical mixtures.		Per cent. alcohol in initial mixture.	Critical mixture.
100	1·0 A.	—	100	42·9 P.
	99·0 P.			57·1 A.
90	0·9 A.	44·6 A.*	90	52·7 P.
	9·8 B.	5·5 B.		4·7 B.
	89·2 P.	49·9 P.		42·6 A.
80	0·7 A.	24·3 A.	80	57·5 P.
	19·8 B.	15·1 B.		8·5 B.
	75·5 P.	60·6 P.		34·0 A.
70	0·7 A.	17·7 A.	70	60·1 P.
	29·7 B.	24·7 B.		12·1 B.
	69·6 P.	57·6 P.		27·8 A.
60	0·5 A.	14·5 A.	60	61·0 P.
	39·8 B.	34·2 B.		15·6 B.
	59·7 P.	51·3 P.		23·4 A.
40	0·5 A.	12·4 A.	40	56·3 P.
	59·7 B.	52·6 B.		26·2 B.
	39·8 P.	35·0 P.		17·5 A.
20	0·5 A.	12·4 A.	20	37·5 P.
	79·7 B.	70·1 B.		49·9 B.
	19·8 P.	17·5 P.		12·6 A.
Nil.	0·5 A.	12·1 A.	Nil.	Completely
	99·5 B.	87·9 B.		miscible.

* This result was a little indefinite, as might be expected from the form of the curve. Points on this section of the curve are evidently given more accurately by starting with alcohol-benzene mixtures and adding petrol thereto.

The total composition of a mixture (percentages of petrol, benzene and 95 per cent. alcohol) represented by any point on the diagram is given, by the perpendicular distances of the point from the sides BC, AB and CA respectively. The points 0 were obtained by starting from mixtures of petrol and benzene and adding alcohol, those marked X by adding petrol to mixtures of benzene and alcohol. The area below the curved line and the narrow strip adjacent to the petrol-benzene axis represent the ranges over which the components are completely miscible. Of these the smaller area adjacent to the petrol-benzene axis is of minor technical importance.

Figures 10 to 13 give the phase diagrams for various concentrations of alcohol at 20°, 10°, 0° and −10° C. respectively, whilst Figures 14 to 17 show the variation of miscibility with temperature of one concentration, 95 per cent. only.

The phase diagrams at 0° and −10° C., contain areas corresponding with mixtures in equilibrium with solid benzene. The type of diagram then obtained is illustrated in Figure 18 for 96 per cent. alcohol, benzene and petrol at −10° C. On the complete diagrams, Figures 12 and 13, the freezing point lines have been drawn corresponding with 96 per cent. alcohol and absolute alcohol. To determine these lines mixtures were made up in pairs to give freezing points just above and just below 0° C. and in the second set −10° C. Freezing point cooling curves were plotted for each mixture, 20 c.c. of solution being used in each case, and the temperatures read off every half-minute. The composition of the mixtures for 0° and −10° C. was then interpolated from these results.

Example in full.

Mixtures of absolute alcohol and benzene.

A. 30 per cent. alcohol 70 per cent. benzene	−0·8° C.
B. 20 per cent. alcohol 80 per cent. benzene	+0·7° C.
Calculated for 0° C. .	−74·9 per cent. B. −25·1 per cent. A.

The results recorded in the earlier part of this paper and illustrated in Figures 2 to 6 were obtained when using B.P. petrol No. 1 supplied in 1921. The petrol used in the experiments illustrated in the phase diagrams of Figures 9 to 18 was a B.P. motor spirit supplied in 1927. It is interesting to compare these two sets of results and in Figure 19 the full curve corresponds with the later, and the points 0, with the earlier determinations for 10° C. It is seen at once that the curve has become displaced parallel with the petrol-benzene axis. The difference between the two sets of results indicates therefore that the 1927 petrol is richer in aromatic hydrocarbons than the 1921 petrol, the displacement of the curve

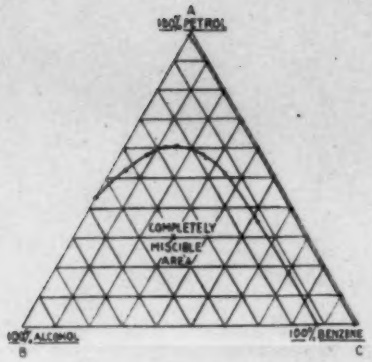


FIG. 9.

The system petrol-benzene 95 per cent. alcohol at 10° C.

Limits of miscibility at
alcohol for alcohols of st

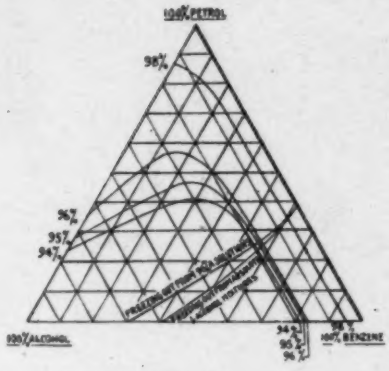


FIG. 13.

Limits of miscibility at 10° C. for the system petrol-benzene-alcohol for alcohols of strengths from 94 to 98 per cent. by volume.

Limits of miscibility fo
alcohol at 20°

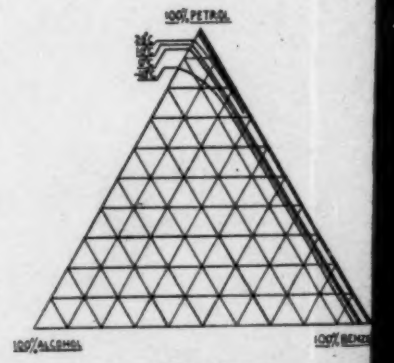


FIG. 17.

Limits of miscibility for the system petrol-benzene 98 p
alcohol at 20° C., 10° C., 0° C. and -10° C.

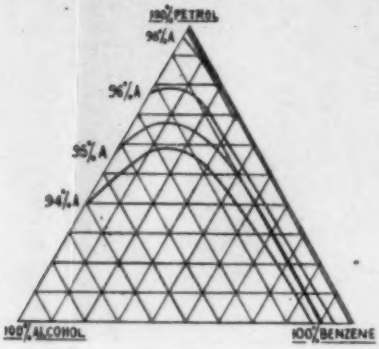


FIG. 10.

Limits of miscibility at 20° C. for the system petrol-benzene-alcohol for alcohols of strengths from 94 per cent. to 98 per cent. by volume.

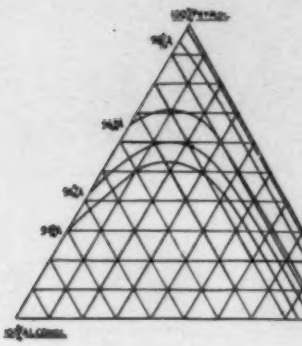


FIG. 11.

Limits of miscibility at 10° C. for the system alcohol for alcohols of strengths from 94 to volume.

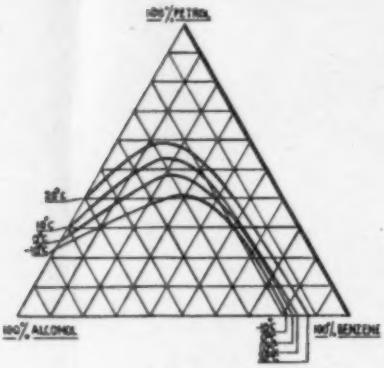


FIG. 14.

Limits of miscibility for the system petrol-benzene 95 per cent. alcohol at 20° C., 10° C., 0° C. and -10° C.

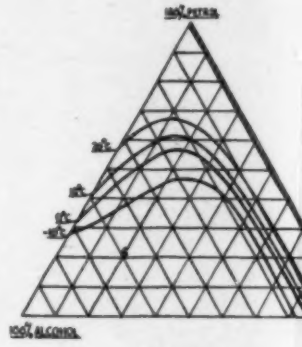


FIG. 15.

Limits of miscibility for the system petrol-benz alcohol at 20° C., 10° C., 0° C. and

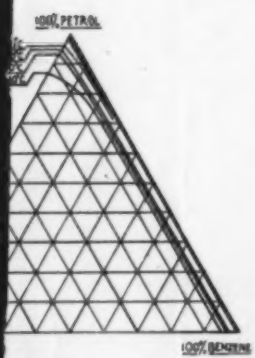


FIG. 17.

the system petrol-benzene 98 per cent. C., 10° C., 0° C. and -10° C.

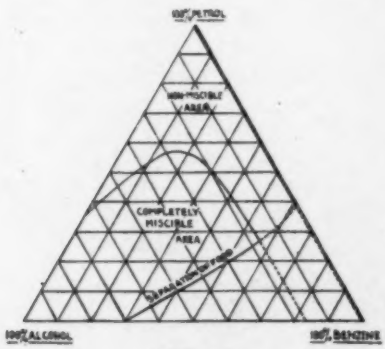


FIG. 18.

Limits of miscibility for the system petrol-benzene 96 per cent. alcohol at 10° C. showing the separation of solid benzene.

Comparison 95 per cent.

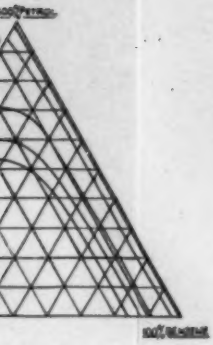


FIG. 11.

C. for the system petrol-benzene-
ngths from 94 to 98 per cent. by
volume.

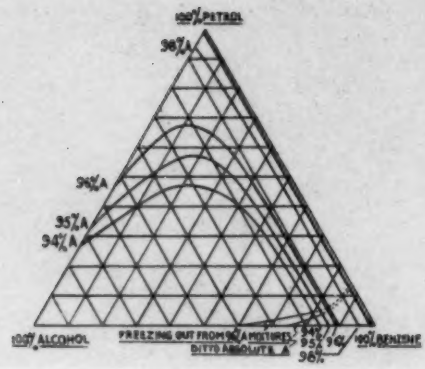


FIG. 12.

Limits of miscibility at 0° C. for the system petrol-benzene-alcohol for alcohols of strengths from 94 to 98 per cent. by volume.

IG. 15.

system petrol-benzene 95 per cent.
10° C., 0° C. and -10° C.

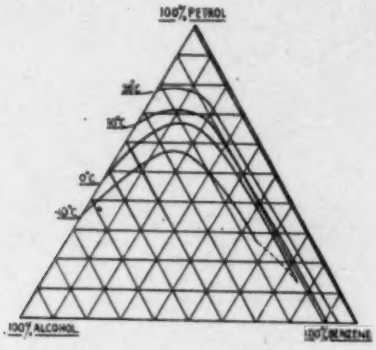


FIG. 16.

Limits of miscibility for the system petrol-benzene 96 per cent. alcohol at 20° C., 10° C., 0° C. and -10° C.

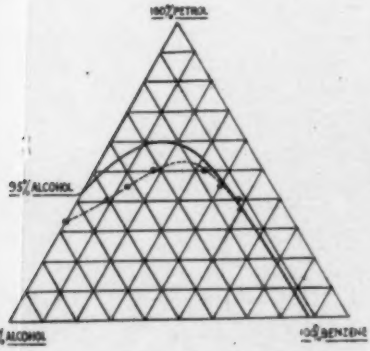


FIG. 19.

Comparison of miscibility curves for the system petrol-benzene 95 per cent. alcohol at 10° C. using B.P. petrols supplied in 1922 and 1927 respectively.

corresponding with an increase of approximately 16 per cent. of benzene in the petrol. A determination of the content of aromatic hydrocarbons in the two petrols gave the following results :—

	Aromatics per cent.
B.P. petrol No. 1 (1921)	6·0
B.P. motor spirit (1927)	21·6
Increase	15·6

The supposition regarding the composition of the two petrols is therefore fully confirmed.

This effect of aromatic hydrocarbons on the miscibility of petroleum spirits with alcohol has recently been made use of by K. R. Dietrich (*Auto. Technik*, 1927, **16**, 7), who has suggested an "alcohol point" for the determination of aromatic hydrocarbons in petroleum spirits which contain only small amounts of unsaturated hydrocarbons.

The authors wish to thank Mr. J. H. G. Carlile for assistance with part of the experimental work.

IV.—Engine Tests.

In order to determine how mixed motor fuels of the above type would behave in an ordinary standard petrol engine, fairly large quantities (about 100 gallons) were mixed and engine tests carried out on a bench engine fitted with the necessary test apparatus. The work was carried out by Messrs. T. F. Hurley, B.Sc., and W. J. Sparkes, B.Sc.

The mixtures were selected so that one would contain the maximum quantity of petrol safe at —20° C., a second the maximum quantity of alcohol and that a third should be petrol containing the maximum amount of alcohol in solution.

	Alcohol.	Petrol.	Benzol 90's.	Specific gravity 15° C.	Analysis per cent.	Calorific value B.Th.U. per lb.
1.	30	40	30	0·798	C 77·39 H 11·56	16,930
2.	50	20	30	0·814	C 70·26 H 11·30	15,420
3.	25	75	—	0·792	C 58·21 H 12·54	14,010

The alcohol used was power methylated spirit of specific gravity 0·818 at 15·5° C. It had a calorific value of 12,120 B.Th.U. per lb. and the following percentage composition by volume :—

95 per cent. alcohol	92·0
Benzol (National Benzole Co.)	5·0
Methyl alcohol	2·5
Pyridine	0·5

The engine used was a 1921, 4-cylinder Dorman engine, type 4 M.R., 130 mm. stroke × 80 mm. bore, compression ratio 4·5 : 1, with magneto ignition. Power output is measured by means of a Heenan and Froude dynamometer. A tachometer driven by a belt from the engine shaft is used to obtain (approximately) the speed when setting the engine. During tests the revolutions are obtained from a positively driven counter.

To measure the fuel consumption a calibrated measuring vessel having two narrow necks is employed. By observing the time taken by the surface of the fuel to pass between two marks on these constrictions an accurate estimation of the volume of fuel consumed per minute is obtained.

The mixture strength can be varied by adjusting needle jets which are substituted for the fixed jets normally supplied with the Zenith carburettor.

The cooling water is supplied to the engine at a constant head so that the quantity and temperature of the water can be readily controlled by a valve fitted in the outlet pipe. Thermometers are fitted into both inlet and outlet pipes, close to the engine, and the outlet temperature is maintained at 140° F. After leaving the engine the cooling water flows into a tank having in its base a circular sharp-edged orifice. A gauge glass fixed to the tank enables the head of water to be seen. From observations of this the quantity of cooling water per minute can be read from a calibration curve. Perforated baffles are used in the tank to eliminate the effect of initial velocity.

Spark advance is measured by a pointer attached to the magneto contact breaker and moving over a calibrated scale.

The full details of the experiments cannot be reproduced here but the following are the conclusions arrived at. One graph is attached, Figure 20, showing the power output from the different mixtures.

Main Conclusions.

(1) *Petrol-alcohol-benzol mixtures.*—Both petrol-alcohol-benzol mixtures are quite suitable for use in a petrol engine, without any alterations being made beyond enlarging the carburettor jets. This includes ease of starting, flexibility and thermal efficiency.

(2) *Petrol-alcohol mixture.*—(*a*) The petrol-alcohol mixture can *not* be used satisfactorily on a standard petrol engine.

(*b*) It is very difficult to start from cold, even after priming with petrol, although the engine can be changed over to the mixture fairly easily after having been started on petrol.

(*c*) The range of mixture strengths over which smooth running is obtained is extremely limited, and also uneconomical.

(*d*) Satisfactory results would probably be obtained if the carburation and distribution were improved, *e.g.*, by heating the ingoing air, "hot-spotting," or redesigning the induction manifold.

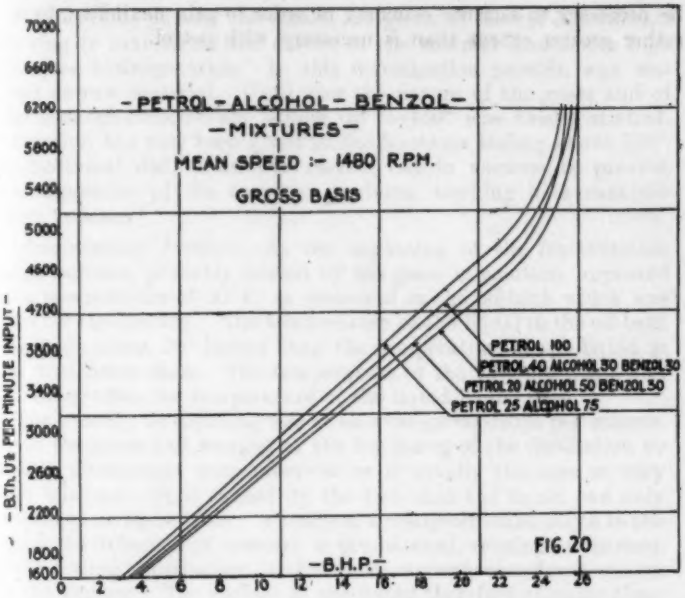


FIG. 20

General Conclusions.

(3) No signs of detonation were observed with any of the fuels. A higher compression ratio could therefore be used with a probable increase in efficiency.

(4) The volumetric fuel consumption necessary for any given power output increases with the volume of alcohol in the fuel. This increase is not sufficiently great to affect seriously questions of storage and transport, the volume of fuel to be carried or the radius of action of a vehicle.

(5) The thermal efficiency obtained with any of these fuels when burned under conditions of maximum economy is not greatly different from that obtained with petrol.

(6) The difference between the mixture strengths giving maximum economy and the theoretical mixture strengths is greater with these fuels than with petrol.

(7) The mixture strength required to obtain maximum economy is nearer the limiting strength for smooth running with these fuels than it is with petrol. In road practice it would probably be necessary to sacrifice economy in order to gain flexibility, to a rather greater extent than is necessary with petrol.

The Thermal Decomposition of Paraffin Wax in the Presence and in the Absence of Hydrogen under High Pressure.*

By H. I. Waterman, T. W. te Nuyl and J. N. J. Perquin.

In previous papers[1] the results are given of several experiments serving to investigate the nature of the thermal destructive high pressure hydrogenation. In this investigation paraffin wax was used as raw material. Until now the nature of the gases and of the gasoline-constituents boiling up to 150° was chiefly studied. Attention has now been given to the fractions boiling above 150°. A fractional distillation was carried out in vacuum to prevent decomposition of the reaction products, working in a cathodic light vacuum.[2]

Berginisation Product.—At the beginning of the fractionation large bubbles, probably caused by the gases in solution, appeared at a temperature of 30° C. as measured in the oil-bath which was used for the heating. The temperature of the liquid in the oil-bath was kept about 20° higher than the temperature of the liquid in the distillation flask. The temperature of the vapours was about 15° lower than the temperature of the liquid in the flask.

The velocity of distilling was at an average 60 drops per minute. After the gases had escaped at the beginning of the distillation no boiling phenomena were observed as is usually the case in very high vacuum. It is caused by the fact that the liquid can only evaporate on the surface; already at a relatively small depth in the liquid the influence of pressure is pronounced, causing an increase of the boiling temperature, so that there can only occur evaporation on the surface. The surface of the liquid therefore remains absolutely quiet. 246·3 grams of the oil boiling above 150° C. were introduced into the flask; in the vessel cooled with liquid-air, which was placed in the path of the vapours leaving the distillate receivers, and going to the Langmuir pump and to the vessels filled with active carbon, 27 grams of the condensate were caught. The distillation loss was 5 grams.

The distillation was continued until the distillate became solid in the condenser.

* Paper received March 25, 1929.

[1] H. I. Waterman and A. F. H. Blaauw, Rec. trav. chim., 1926, **45**, 284; H. I. Waterman and J. N. J. Perquin, ibid., 1927, **46**, 813. Comptes rendus du 7me congrès de Chimie industrielle, Octobre, 1927, *Chimie et Industrie*, numéro spécial, April, 1928, p. 244.

[2] H. I. Waterman and H. J. Rijks, *Z. deutsch. Öl- und Fettindustrie*, 1926, 177.

Cracking Product.—172·9 grams were separated in an analogous way by fractional distillation. The loss of weight was 0·26 grams. The authors' opinion is that the boiling limits of both products (berginisation and cracking) do not differ much.

The distillation could not be carried out continuously, which explains that in some cases at the same temperature two fractions were caught. The aniline point, the refractive index at 20° C., the bromine value and the specific weight were determined.

				n_D^{20}		Aniline point.		Bromine value.		Spec. weight.	
		B	C	B	C	B	C	B	C	B	C
	Temperature of the vapour	% of weight	% of weight								
I.	—	11·0	18·2	1·4170	1·4368	67·2	48·8	12·6	20·2	0·742	0·782
II.	20–30°	—	1·2	—	1·4464	—	58·2	—	16·4	—	—
III.	30–40°	7·8	4·9	1·4275	1·4466	74·4	56·0	9·4	15·8	—	—
IV.	40–50°	10·1	13·6	1·4267	1·4510	75·8	56·6	9·3	16·2	0·761	0·808
V.	50–60°	5·8	10·1	1·4286	1·4578	77·2	58·4	9·9	14·7	—	—
VI.	60–70°	12·4	4·2	1·4323	1·4648	81·4	61·6	7·7	13·7	0·774	0·833
VII.	70–80°	4·7	14·6	1·4366	1·4740	85·8	65·4	8·3	11·4	—	—
VIII.	80–90°	7·1	9·0	1·4392	1·4788	88·8	67·4	7·0	9·8	0·785	0·852
IX.	90–100°	7·1	6·8	1·4422	1·4930	92·2	74·0	6·5	8·3	—	—
X.	[75–90°]	5·5	—	1·4458	—	96·4	—	5·8	—	—	—
XI.	[90–100°]	3·6	—	—	—	—	—	—	—	—	—
XII.	Residue	23·0	17·3	—	—	—	—	—	—	—	—
	Loss	1·9	0·1	—	—	—	—	—	—	—	—

B = Berginisation. C = Cracking.

The average distillation temperature of the fractions condensed by cooling with liquid air could be estimated from the change of the spec. weight in connection with the boiling point by an extrapolation. If the analogous berginisation and cracking fractions are compared we see :—

(*a*) The aniline point on berginisation is about 20° higher than on cracking.

(*b*) The refractive index of the cracking products is about 0·02 to 0·03 higher.

(*c*) The bromine value of the cracking products is much higher.

(*d*) The specific weight of the products is higher on cracking.

All these facts indicate the stronger unsaturated, and especially the more cyclic character (aromatic, hydro-aromatic, etc.), of the cracking products. On the determination of the bromine number the substitution characterised by the formation of HBr is also observed. This substitution was always much more pronounced on cracking than on berginisation. This also indicates the partly aromatic nature of the cracking products.

To get an insight into the nature of the hydrocarbons in the berginisation and cracking fractions, the table below gives a compilation of the boiling points and some other physical constants[3] of the normal saturated hydrocarbons, the first being nonane, because this boils at about 150° (760 m. M.).

NORMAL SATURATED ALIPHATIC HYDROCARBONS.

	Boiling point at 760m. M.	Boiling point at 4m. M.	Aniline point.	Sp. Gr. 15·5/15·5	n_D^{20}
C_9	149·48	23·45	74·0	0·72	1·40
C_{10}	173·0	40·65	77·5	0·74	1·41
C_{11}	194·5	57·25	81·6	0·75	1·42
C_{12}	214·5	73·5	86·0	0·76	1·43
C_{13}	233·78	92·6 (5m. M.)	89·5	0·77	1·43
C_{14}	252·5	129·5 (15m. M.)	93·0	0·775	1·44
C_{15}	270·5	143·5 (15m. M.)	96·5	0·78	1·44

If the physical constants of the B-products are compared with those of the normal saturated paraffin-hydrocarbons, it is seen that the nature of the B-constituents much resembles the said group of hydrocarbons, although the n_D^{20}, the aniline point, the bromine number and the specific weight indicate the presence of a small percentage of unsaturated hydrocarbons. It is probable that the first fractions will contain nonane, therefore the properties of these fractions are specially compared with the C_9-constants :—

	n_D^{20}	Aniline point.	Bromine value.	Spec. Gr.
I.B. ..	1·4170 ..	67·2 ..	12·6 ..	0·742
Nonane ..	1·40 ..	74·0 ..	0·0 ..	0·72

If the unsaturation of the berginisation fractions is presumed to be chiefly caused by olefines, an olefine (nonylene) content in I. B. of about 10 per cent. may be calculated. Thus the higher n_D^{20} and Sp. Gr. and the lower aniline point is partly explained. This is also the case in an analogous way for the higher B-fractions, which would then contain a high percentage of saturated hydrocarbons, together with olefines and other hydrocarbons.

As a contrast to these facts the C-fractions are more unsaturated, have a higher Sp. Gr., a higher refractive index and a lower aniline point.

Therefore it may be concluded from this investigation that analogous contrasts, as occur between the *B*- and *C*-gasoline-fractions, also exist between the *B*- and *C*- higher boiling products, kerosine included. The differences are more pronounced with the higher boiling fractions.

DELFT, Laboratory of Chemical Engineering,
The Technical University.
February, 1929.

[3] C. van Rechenberg, *Destillation*, Leipzig, 1923 ; J. A. Carpenter, *J. Inst. Petr. Techn.*, 1928, **14**, 446.

A Comparison of the Conditions of Occurrence of Bituminous Coal and Petroleum.*

By E. McKenzie Taylor, M.B.E., Ph.D., D.Sc., F.I.C. (School of Agriculture, Cambridge).

Introduction.

Frequent reference has been made in the literature dealing with petroliferous strata to the similarity in the conditions of occurrence of coal, lignite and petroleum. These references may be summarised as follows: "So far as lithological evidence goes, the strata of many Tertiary oilfields are exactly the same as those associated with coals and lignites."[1] The examinations of coal-bearing and petroliferous strata which have been carried out recently[2, 3] enable comparisons of their chemical, physical and biological properties to be made. The results obtained emphasise the similarity between these types of strata and indicate that bituminous coal and petroleum have probably resulted from the decomposition of different materials under a common final set of conditions.

A Consideration of the Term "Lignite."

It is necessary first to consider the difference between bituminous coal and lignite, as these materials are frequently mentioned in connection with petroliferous strata. The usual distinction that has been made between the two materials has been based mainly on differences in chemical composition as indicated by the C/H ratio.[4] Classifications of these materials, which are based on chemical composition, enable the coals to be graded and their values assessed for particular purposes. These methods of grading the materials may be termed "commercial classifications." They do not take into account differences in the characters of the strata in which they occur nor differences in the possible modes of formation.

In connection with the investigation of the characteristics of the roofs of coal seams, specimens of the roofs of American "black lignites"[5] and of brown coals and lignites[6] were examined. In the case of the "black lignites" it was demonstrated that the roofs of these seams had undergone base exchange with solutions of sodium chloride and that the sodium clay thus formed had been subjected later to hydrolysis in freshwater. The American "black

* Paper received 22nd March, 1929.

lignites" occur, therefore, in strata with chemical, physical and biological properties similar to those of the strata in which bituminous coal is found. From the conditions of occurrence and probable mode of formation, therefore, the "black lignites" belong to the bituminous coal series.

An examination of the roofs of brown coals and lignites has shown that the main clay type present in the roof is calcium clay. The roofs of seams of brown coal have, therefore, not undergone base exchange with solutions of sodium chloride. They appear to have been formed from accumulations of plant materials in freshwater and under such conditions that the sediment now forming the roofs was deposited in freshwater and was not subjected afterwards to base exchange, either by submergence in the sea or by contact with capillary solutions of sodium chloride raised from a subsoil water-table containing that salt in solution. It has been demonstrated in the laboratory that the decomposition of plant materials by bacteria under a calcium clay roof is carried out under different conditions to that under a sodium clay roof and that the products of the two types of decomposition are also different. It has been suggested that the term "lignite" should be applied only to those coals which have resulted from the decomposition of plant materials under a roof in which the main clay type is calcium clay.

In the literature dealing with the occurrence of petroleum, coals and lignites are frequently recorded as having been found in similar strata. These strata have usually been laid down under deltaic or estuarine conditions. As the characteristic clay formed under deltaic and estuarine conditions is sodium clay, it appears that the roofs of the "lignite" seams will be characterised by alkalinity and high content of replaceable sodium. The lignites mentioned in connection with petroliferous strata should probably be classed as bituminous coals, of which series they may be the lowest members. It will be assumed in this paper that the lignites to which reference has been made occur under a sodium clay roof. They will be regarded, therefore, as low members of the bituminous coal series.

The Characteristics of Bituminous Coal Seam Roofs.

It has been previously recorded[7] that the investigation of the nature of the replaceable bases in the roofs of bituminous coal seams originated in the discovery in Egypt of a recent peat deposit containing fusain, which was overlain by a soil in which the characteristic clay constituent was sodium clay. The deposit had been formed under deltaic conditions and it was known that the alkaline soil had been produced as the result of base exchange with sodium chloride solutions. Clays of the same type were also found

with fusainised material in them. An extensive series of bituminous coal seam roofs of various geological ages was examined to determine whether the conditions of occurrence of bituminous coal was similar to that of the Egyptian fusainised material. The pH values of the roofs were determined and estimations of the replaceable calcium and sodium present were made. The results of the examinations of typical specimens is shown in Table I.

TABLE I.

Origin of Specimen.	pH Value.	Replaceable Bases. (M.E. per 100 grams shale.) Ca.	Na.
Specimens of Carboniferous Age.			
Thorncliffe Seam (Yorks)	9·2	Trace	14·8
Five Quarter Seam (Durham) ..	9·6	Trace	17·1
Little Coal (Yorks)	9·6	Trace	16·2
High Main (Northumberland) ..	8·4	Trace	9·3
Specimens of Cretaceous Age.			
Eagle Sandstone Formation, Wyoming	9·8	24·9	79·1
Raton Formation, Colorado.. ..	9·8	5·6	18·8
Mesaverde Formation, Utah ..	8·6	6·2	10·9
Specimens of Tertiary Age.			
Fort Union Formation, Montana ..	8·8	4·8	21·9
Fort Union Formation, Montana ..	9·8	4·8	19·7

From Table I. it will be seen that the specimens are alkaline and that the amount of replaceable sodium present is always in excess of the replaceable calcium. The results, therefore, show that the roofs of bituminous coal seams of all geological ages have undergone base exchange with solutions of sodium chloride and that the sodium clay thus produced has been subjected to hydrolysis in freshwater. As the result of the study of the bacterial decomposition of plant remains under a sodium clay roof, the theory was put forward that bituminous coal had been formed by the bacterial decomposition of plant remains under anærobic conditions and in the continuously alkaline medium provided by the hydrolysis of the sodium clay present in the roof of the seam. It was demonstrated that peat could be decomposed by bacteria under such a roof, and that during this decomposition oxygen was eliminated from the peat.

A COMPARISON OF THE SHALES FORMING THE ROOFS OF COAL SEAMS AND SHALES FORMING THE CAP-ROCKS OF OIL-SANDS.

An examination of the shales overlying petroliferous strata has recently been made. It is generally accepted that petroliferous strata have accumulated under deltaic, estuarine or marine conditions. Under these conditions, sodium clay would be the main clay type produced. As the result of an examination of a number of specimens of shale overlying oil-sands, the presence of sodium clay has been demonstrated. Further, it has been shown that the

sodium clay has undergone hydrolysis in freshwater. The shales overlying oil-bearing strata, therefore, contain the same type of clay and have been submitted to the same alternating conditions of salt and fresh water as the strata which form the roofs of bituminous coal seams. From these results, therefore, it can be concluded that the shales overlying petroliferous beds have chemical, physical and biological properties similar to those of the shales forming the roofs of bituminous coal seams. The chemical, physical and biological properties of sodium clay have been discussed previously. It seems probable, therefore, that bituminous coal and petroleum have been formed as the result of the same final type of decomposition since they occur in unaltered sedimentary strata with identical properties.

The foregoing conclusion is important in connection with the consideration of the types of material from which coal and petroleum may have been formed. Since the conditions in the strata under which the two materials—coal and petroleum—have been formed are identical, it follows that the materials submitted to the identical types of decomposition must have differed.

The two main types of organic material that could accumulate under deltaic conditions are (*a*) the debris of terrestrial vegetation, and (*b*) the remains of the marine and estuarine flora and fauna. The debris of the terrestrial vegetation could accumulate on the higher portion of the delta or, as the result of drift, in salt water in the estuary and in the sea. The amount of terrestrial vegetation that has been transported and deposited under marine conditions appears to be small as is shown by the examination of the roofs of bituminous coal seams. In this connection, Cunningham-Craig[8] states: "Any coal or lignite measures in any part of the world consist of rapid alternations of thin beds of rapidly accumulated sediment, varied with *occasional* bands truly marine in origin, and horizons denoting terrestrial conditions." The marine flora and fauna can only accumulate to any extent under marine conditions. There appears, therefore, to be two broad groups of organic matter from which coal and petroleum may have been produced: (*a*) the terrestrial flora, and (*b*) the estuarine and marine flora and fauna. Each of these groups will form their maximum accumulations under two different conditions—the terrestrial flora on land, and the marine flora and fauna in the sea.

It is generally accepted that coal has been formed by the decomposition of the debris of terrestrial flora. The constituents of terrestrial plants when buried in sedimentary strata containing sodium clay yield, therefore, solid carbonaceous residues on decomposition. Waksman[9] has shown that the substance most likely to have been the source of "humus" is the ligno-cellulose of

the plant material. Fischer and Schrader[10] regard lignin alone of the plant consituents as the raw material from which coal has been formed. Studies of the bacterial decomposition of plant materials under sodium clay support this opinion.[11] It appears, therefore, that bituminous coal is the residue of the decomposition of plants containing ligno-cellulose under the conditions imposed by a sodium clay roof. As it has been shown that both the roofs of bituminous coal seams and the cap-rocks of petroliferous beds contain sodium clay, it appears that terrestrial plants yield a bituminous coal under the conditions that would be imposed by the shales overlying petroliferous beds. It has been remarked that "in the oilfield phase not a trace of vegetable matter is observed."[12] From the conditions of occurrence of coal in strata containing sodium clay, and since the clays of the petroliferous strata are also sodium clays, it would be expected that the remains of terrestrial vegetation would have been found in oil-sands had terrestrial vegetation been present at any time. As the remains of terrestrial vegetation are not found in oil-sands, it points to the conclusion that terrestrial vegetation has at no time been present. This deduction is important in view of the suggestions that have been made as to the part played by terrestrial vegetation in supplying the material from which petroleum has been formed.

It has been suggested that petroleum has been formed from terrestrial vegetation either (*a*) directly, or (*b*) indirectly as the result of the distillation of coal seams. In support of the theory of the formation of petroleum directly from terrestrial vegetation, the destructive distillation of peat under certain defined conditions has been instanced.[13] It is not stated, however, that no trace of vegetable material is left on the completion of the process—an essential, if it is to account for the formation of petroleum under natural conditions. Since no remains of terrestrial vegetation are found in petroliferous beds, and since, if terrestrial vegetation had been present, the conditions in the strata indicate that remains should be found, the conclusion that terrestrial vegetation has taken no part in petroleum formation is indicated.

In considering the source of the material from which petroleum has been formed, three conditions must be satisfied: (*a*) the material should have grown in such a situation that it could accumulate under the conditions necessary for the formation of a sodium clay; (*b*) the conditions of accumulation should be such that the sodium clay would be so situated that by small earth movements it could be subjected to hydrolysis in freshwater; and (*c*) the material should not have contained ligno-cellulose. These conditions are satisfied by a shallow marine and estuarine flora and fauna.

Cunningham-Craig,[14] discussing the indications that are usually favourable for the presence of petroleum, states that the strata have been formed under estuarine or deltaic conditions. When the conditions under which the strata have been formed are entirely marine, petroleum is rarely found. It seems probable, therefore, that the source of the material from which petroleum has been formed is to be found in the flora and fauna associated with deltaic and estuarine conditions of deposition. Twenhofel[15] divides deltaic deposits into four sections: (*a*) the topset deposits of the subærial plain; (*b*) the topset deposits of the subaqueous plain; (*c*) the deposits of the foreset slope, and (*d*) the bottomset beds beyond the foreset slope. The characteristics of the fauna and flora of these four areas of deposition may be summarised as follows: (*a*) the foreset deposits of the subærial plain will be characterised by land and freshwater fauna and flora, some of the latter occurring in the places in which they grew; (*b*) in the topset deposits of the subaqueous plain, an estuarine flora and fauna with a certain amount of drifted land flora will be present; (*c*) the deposits of the foreset slope will be characterised by a flora and fauna associated with estuarine and marine conditions; and (*d*) the fauna and flora of the bottomset beds will be of marine types. It will be seen that the accumulations of terrestrial flora under deltaic conditions are mainly confined to the topset deposits. The accumulation of the estuarine and marine forms will take place in the deposits of the foreset slope and the bottomset beds. As the formation of the delta proceeds, the topset deposits are extended towards the sea and overlie the initial foreset and bottomset deposits. In any deltaic section, therefore, where the four series of deposits are present, it would be expected that the highest beds of the series would contain remains of a terrestrial flora and fauna, and that the lower beds, representing the deposits of the foreset slope and bottomset beds, would contain practically no traces of terrestrial forms, but would be characterised by estuarine and marine forms only. Since the deposition of the terrestrial flora containing ligno-cellulose in a sodium clay appears to have led to the formation of coal, it would be expected that, in any series of deltaic deposits containing coal and petroleum, the coal would occupy the position corresponding to the topset beds. If the material from which petroleum has been formed is of marine origin, it would be expected that the petroleum would occupy the beds of the deltaic formation corresponding to the deposits of the foreset slope and bottomset beds. This appears to accord with the relationship between the occurrence of coal and petroleum in the *same* deltaic series. Cunningham-Craig[16] states: "There are many instances on record of a series being petroliferous in the

lower beds, and lignitic or coal-bearing in the upper members." He instances the Tertiary Series of the State of Falcon in Venezuela and the section at Point Ligoure on the western coast of Trinidad; similar occurrences, he states, are also to be noted in Borneo, Russia and West Virginia.

Further, Sir Edwin Pascoe[17] says: "In Assam . . . in nearly every separate oil area . . . it is especially in the horizons higher up that coal in any bulk is found . . .; not only is there this vertical relationship, but there is another accompanying it of a geographical nature, according to which coal seams show a preference for the margins of the gulf in which the Tertiary sediments accumulated, while petroleum is usually found a little further from the coast." In this quotation, the vertical relationship and the geographical distribution of coal and petroleum suggest that coal has been formed from terrestrial plants and that the material from which petroleum has been formed is of marine origin.

The positions occupied by the coal-bearing and petroliferous beds in any series of deltaic deposits containing both types are such as would be expected if coal had been formed from terrestrial vegetation and petroleum from the marine flora and fauna. If petroleum had been formed from terrestrial plants, its presence would not be expected in the lower members of a deltaic series. From the deltaic conditions of formation of the strata in which petroliferous beds occur, and from the positions which these beds occupy in the deltaic series, the possibility that petroleum has been formed from land plants seems to be excluded and it is strongly indicated that its origin must have been in the decomposition of the accumulations of the marine flora and fauna. This is supported by one significant difference between the terrestrial flora, the source of coal, and the marine flora and fauna. In the former, ligno-cellulose is present; this yields on decomposition in a sodium clay the solid carbonaceous residue typical of bituminous coal. In the latter, ligno-cellulose is absent; there does not appear to be any record of the decomposition products of ligno-cellulose being present in petroliferous beds that would be expected as the result of the overlying shales containing sodium clay.

Evidence of Accumulation of Organisms not containing Ligno-cellulose under Estuarine and Deltaic Conditions at the Present Time.

The hypothesis that petroleum has resulted from the decomposition of marine flora and fauna has met with opposition on two grounds: (*a*) that it was impossible for the necessary quantity

of material to accumulate and be entombed in sediments, and (*b*) the lack of fossil evidence of the former presence of marine algæ in petroliferous strata.

It appears to have been assumed that under deltaic conditions the environment has been unsuitable for the development of marine algæ.[18] Twenhofel[19] remarks, however, "All of the carbonaceous sediments were more or less directly deposited by organisms." As the carbonaceous sediments have been formed mainly under deltaic or estuarine conditions, it appears that the environment associated with these conditions is not so unfavourable for the development of organisms as has been suggested. Further evidence bearing on the suitability of estuarine and deltaic conditions for the development of organisms is afforded by the study of marshes formed under these conditions. The marshes formed under deltaic or estuarine conditions may be divided into two principal areas: (1) a higher level terrace or salt marsh covered only by spring tides, and (2) the lower flats which are covered by every tide. The high marsh is covered with vegetation mainly of a terrestrial type, though certain algæ may be present as, for instance, the non-attached fucoid *Pelvetia canaliculata* recorded at Blakeney.[20]

Algæ are the principal flora of the low marsh. Carey and Oliver[21] state: "A certain number of algæ have fitted themselves for existence on muddy shores, and these, though specifically few, occupy a great expanse of ground." The algæ of the low marsh appear to belong to two groups: (*a*) those that merely cling to the surface of the mud, and (*b*) those that penetrate into the mud and become part of its fabric. The most important of the present day species of the first class are *Enteromorpha*, *Rhizoclonium* and *Ulva*. The following quotations[22] indicate the importance of the second class of algæ in the formation of sedimentary deposits: (*a*) "In the history of marsh development, *Fucus limicola* plays an important part in catching and holding silt, and also in the enrichment of the soil." (*b*) "These two algæ (*Vaucheria Thuretii* and *Microcoleus chthonoplastes*) between them occupy extensive surfaces otherwise bare, and within the limits of their zones are the most efficient catchers and holders of mud." (*c*) "These vegetated areas form the collecting surfaces where silt is retained and permanent rise in level effected. Indeed, *this co-operation of plants is practically universal where new land is being organised from supplies of mud and sand. . . . . The vegetation of previous years becomes in large part buried . . .*"

An investigation of the effect of algæ in assisting in the formation of deposits under estuarine conditions was carried out by Dr. S. M. Baker.[23] Figures which he obtained for the "loss on ignition" in these deposits are shown in Table II.

TABLE II.

Name of Marsh Vegetation.	Per Cent. Loss on Ignition.
Young Marsh under *Fucus limicola*	8·39
Mud with *Vaucheria Thuretii*	7·30
Mud with *Microcoleus chthonoplastes*	4·86

Carey and Oliver remark on these results that "they refer to *quite young* marsh soils occupied by various species of algæ. The source of the organic matter in these cases is the filaments and thalli of the algæ which have been buried in the ordinary process of accretion." They further state, "We are impressed with the high efficiency of the embedded *Fucus limicola* in favouring accretion."

Further information on the growth of algæ in estuarine areas where such deposits are now forming is afforded by the investigations on the growth of *Ulva*.[24] In this case the *Ulva* is associated with the presence of mussels on mud flats. It is stated that, "The mooring provided by the byssus of the mussels is particularly secure. But *the special importance of these molluscs lies in the fact that they colonize and provide anchorage on mud*." And again, "In muddy estuaries these molluscs are known to cover extensive areas of the foreshore, and when this is the case large stretches of ground suitable for the growth of *Ulva* may thus be provided."

Analyses of the muds containing *Ulva* remains showed that two samples contained 9·85 per cent. and 10·73 per cent. of organic matter.[25]

It will be seen, therefore, that the environment provided by deltaic and estuarine conditions is not unsuitable, as has been suggested, for the development of both a flora which does not contain ligno-cellulose and an estuarine fauna. In fact, it appears that the development of the deltaic and estuarine deposits is dependent to some extent on the presence of these organisms. A source of supply of organic matter free from ligno-cellulose is available, therefore, for decomposition under deltaic and estuarine conditions.

In connection with marine algæ, Johnstone[26] states that "The larger seaweeds are not eaten to any great extent by animals. There is no doubt that an immense quantity of marine algæ . . . is not utilised by animals, but simply dies and putrifies sometimes on a very large scale." From the foregoing discussion it will be seen that the possibility of the estuarine and marine flora and fauna having contributed largely to the organic materials embedded in sedimentary deposits of deltaic and estuarine origin cannot be summarily dismissed. The association of *Ulva* with mussels is particularly interesting as it shows that under certain conditions the organic matter in any bed may have been derived from two

entirely different materials. Under estuarine and deltaic conditions it is not only possible, but appears most probable, that sediments will be formed containing organic matter derived from a marine or estuarine source and in which the remains of terrestrial plants will be entirely absent. In the Blakeney marshes a sharp division appears to be drawn between the beds containing the remains of a terrestrial flora and those containing the remains of marine plants. The same sharp division appears to exist in strata containing both coal and petroleum. From the conditions under which estuarine and deltaic strata are accumulating at the present time there appears to be a considerable amount of evidence supporting the suggestion that the organic material from which petroleum has been formed is of marine origin.

The absence of fossil evidence of the former existence of a marine flora is an objection that has been raised to the suggestion that petroleum has been formed by the decomposition of marine plants. If petroleum has been formed from marine plants and no fossils of these plants are now found, it must be concluded that the materials are capable of complete decomposition under the conditions of petroleum formation. The decomposition of algæ in a sodium clay is now being studied.

An observation indicating that complete decomposition of algæ does take place in a sodium clay was made when studying the decomposition of vegetable materials in connection with coal formation. In certain of these decompositions, the incubation was not carried out in the absence of light. A large growth of algæ was obtained in the sodium clay roof. Further incubation of these materials was carried out in the absence of light. The algæ decomposed leaving a residue of ferrous sulphide where they had been previously present. The ferrous sulphide oxidised on drying and no trace of the former presence of algæ remained. The formation of ferrous sulphide as a result of the decomposition of algæ is shown in Fig. I. It appears probable, therefore, that the absence of fossil evidence of the former presence of a marine flora in petroliferous strata is as would be expected from the nature of the materials of which algæ are composed and from the conditions under which the decomposition would take place.

As the organic matter of the marine flora and fauna is mainly composed of carbohydrates, fats and proteins, the decomposition of pure examples of these materials in sodium clay is now being studied. The main difference in composition between the terrestrial flora and the marine flora is that lignoc-ellulose is present in the former and not in the latter. Ligno-cellulose is also absent from the marine fauna. Further, the organic matter of the estuarine and marine fauna is similar to that of the estuarine and

marine flora, both being mainly composed of the three groups of substances, carbohydrates, proteins and fats. Since there is no reason for assuming any fundamental difference in the carbohydrates, proteins and fats of vegetable and animal origin, it

FIG. 1.

Ferrous sulphide formed by decomposition of algæ in sodium clay.

appears that both the estuarine and marine flora and the estuarine and marine fauna may have been sources of the material from which petroleum has been formed. The decomposition by bacteria of these three types of material in a sodium clay is now being investigated.

Summary.

(1) It has been shown that both the roofs of bituminous coal seams and the cap-rocks of oil-sands have undergone base exchange with solutions of sodium chloride and that the sodium clay thus formed has been subjected to hydrolysis in freshwater.

(2) The similarity of the strata in which bituminous coal and petroleum occur has been frequently mentioned. As a result of the examination of the roofs of bituminous coal seams and the cap-rocks of oil-sands, this similarity is emphasised since it has been shown that both types of strata have identical chemical, physical and biological properties.

(3) Since bituminous coal and petroleum have been formed by the decomposition of organic matter in unaltered sedimentary strata with identical chemical, physical and biological properties, it appears that they have been formed by the same type of decomposition. They must, therefore, have been formed from different types of organic matter.

(4) It has been shown from observation in the field that plant material containing ligno-cellulose when decomposed in a sodium clay yields materials similar to those in bituminous coal. Laboratory evidence on the decomposition tends to confirm this observation. Since bituminous coal appears to have been formed from terrestrial plants, characterised by the presence of ligno-cellulose, by decomposition in a sodium clay, a source of organic matter free from ligno-cellulose is indicated as the material from which petroleum has been formed.

(5) The geological evidence of the conditions of occurrence of petroleum suggest that the raw material from which it has been formed is of estuarine and shallow marine origin. Material of estuarine and marine origin satisfies the condition, deduced from the chemical and biological study of the strata, that the raw material should be free from ligno-cellulose. As a result of this investigation support is given, therefore, to the estuarine and marine origin of the material from which petroleum has been formed.

(6) Sediments deposited under estuarine and shallow marine conditions would undergo base exchange and would be so situated that hydrolysis in freshwater would be possible as the result of small earth movements. If the raw material of petroleum were of estuarine or marine origin, it would be situated in sediments which have been deposited under conditions suitable for the formation of strata with chemical, physical and biological properties such as the petroliferous strata have been shown to possess.

(7) The vertical relationship and the geographical distribution of bituminous coal and petroleum in deposits containing both of these materials, as worked out in Assam and in other areas, supports an estuarine and marine origin of the organic matter from which petroleum has been formed.

(8) In considering the type of material of estuarine and marine origin that may have contributed to petroleum formation, it appears to be unnecessary to distinguish between the estuarine and marine flora and the estuarine and marine fauna as these are composed of fundamentally similar chemical compounds.

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INSTITUTION OF PETROLEUM TECHNOLOGISTS.

Trinidad Branch.

The Ninth Ordinary Meeting of the Trinidad Branch of the Institution of Petroleum Technologists was held at the Apex Club, Fyzabad, Trinidad, B.W.I., on Wednesday, January 30th, 1929, Mr. A. Frank Dabell (Chairman) occupying the Chair.

Notes on a New Mud Volcano in the Sea off the South Coast of Trinidad.

By W. G. Weeks, A.R.S.M., A.R.C.S., F.G.S., F.R.G.S. (Associate Member).

This paper comprises a few observations on the new islet that appeared off the South Coast of Trinidad about a month ago, the results of the examination of the material collected there, and some remarks on its relation to similar occurrences.

The island apparently came into existence at some time in the morning of December 21st, 1928. This rests on the assertion of the people living near Chatham, who were questioned on the following day. They state that loud noises were heard and that they saw masses of rock being hurled into the air.

Its position has been fixed by intersection from the South end of the Chatham Road, and from the point where the Erin Road joins the beach. The usual survey practice of the island was followed, and the observations were taken with a theodolite fitted with a trough compass adjusted so that the lower plate could be set by the compass to true North at the reference station in Port of Spain. The bearings to the centre of the island, corrected for the difference between the local magnetic variation and that of the reference station and for diurnal variation, were as follows :—

From Chatham Beach	176° 31′ or S. 3° 29′ E.
From Erin Beach	265° 18′ or S. 85° 18′ W.

The angle between the shots was thus the very favourable one of 88° 47′ or nearly a right angle.

Plotting these on the 1/50,000 Government map, the island is seen to be rather less than a mile and a-half from Chatham beach, which is the nearest point of the coast. From Erin beach it is about five miles. Its geographical co-ordinates are 10° 03′ 45″ N., 61° 44′ 01″ W. The position of the island accords roughly with the mud volcano line drawn through the Palo Seco group, a shoal lying about three miles west of the Erin point, the

mud volcano island of 1911, the volcanoes of Islote Point and the Cedros group.

A landing was made on December 29th. The island was found to be roughly circular in shape and from 75 to 100 yards in diameter, estimated by eye. Its underwater form is also circular. Soundings taken from Chatham beach showed a gradual increase to 3½ fathoms, and the same depth was observed in a series of soundings taken all round the island. The highest point was estimated to be not more than 6 ft., so that its total height above sea bottom is about 26 ft. Its shape is thus a truncated cone, probably from 150 to 200 yds. in diameter at the base. Its area was about an acre.

The surface was covered in small craters in sandy clay, 2 or 3 ft. in diameter, none of which, so far as could be seen, was active. Unfortunately, the sun, in drying and hardening their upturned edges, had made the surface too rough for bare feet, so that observations had to be confined to what could be seen from the small sand spit at the western end where the landing took place. At this spot, the sea had washed out the clay, leaving a small beach of comparatively firm sand, but, away from here, the surface, where not sun-baked, was yielding and treacherous.

In addition to the sandy clay there were many angular pebbles and boulders up to about 8 in. in diameter. Among these were a sandstone and grit with chert grains, probably akin to the "Herrera" sandstone, well-bedded light grey lignitic sandstone, fine grained sand-stone irregularly impregnated with bitumen calcareous sandstone, coarsely crystalline agglomerations of pyrites and masses of aragonite. The last were sometimes in the form of irregular plates with a fibrous appearance at right angles to the face of the plate, and seem to have been broken off from stringers or incrustations.

A sample of the sandy clay was washed out, and the residue examined microscopically. The following genera of foraminifera were provisionally identified:—

Ammodiscus	*Hormosina* (2 spec.)	*Orbulina*
Amphistegina	*Lagena* (2 spec.)	*Plectofrondicularia*
Bolivina (2 spec.)	*Laticarinina*	*Pullenia* (?)
Clavulina	*Lenticulina*	*Pyrgo*
Cyclammina	*Marigulina*	*Rhabdammina*
Globigerina (2 spec.)	*Nodosaria* (6 spec.) (or *Siphonodosaria*)	*Robulus* (2 spec.)
Sorosphaera (3 spec.)		*Aphaeroidina*
Tritaxia		*Truncatulina**
Uvigerina (2 spec.)		*Virgulina*.

*This genus has now been sub-divided by Cushman. The particular form found has usually been identified in Trinidad as *Trunculatina wuellerstorfi*. Its new generic name is not known.

There were also many small irregularly cylindrical fragments, often pyritized, that may have been the casts of worm burrows. Two small gastropods were found, a fish scale, and a few *Echinoid* (*Cidaris* ?) spines and plates. A number of unidentified forms that could not be included in the above list were present.

The species of *Cyclammina* was *cancellata*, but it, like the *Ammosdiscus*, differed in colour from specimens found in the upper part of the Naparima series. Presumably this is due to their having had to employ a different kind of sand in the construction of their tests, and points to their not having originated in upper Naparima beds.

Amphestegina was the most common form. It is suggested with some diffidence that it demonstrates the existence of St. Croix beds among the series passed through by the volcanic material. It will probably not be disputed, however, that this form is indicative of beds earlier than the Forest and Cruse series. Perhaps it would be as well for the moment not to reopen the vexed question of its relation to the Marls. It is noteworthy that neither *Siphogenerina* nor *Planorbulina* was found, although they are commonly associated with *Amphistegina*. Caution should, therefore, be exercised in drawing deductions from the absence of other forms from the list.

The whole assemblage and the state of the fossils suggests that it is a mixed fauna, a supposition that is strengthened by the presence of *Virgulina*.

Erosion was already active when the island was visited. Wave action had cut little vertical cliffs, particularly on the eastern and southern sides, and these were deeply scored by miniature gulleys. There is no doubt that a few heavy rains and severe storms would remove most of the material now above sea-level.

Turning now to previous similar occurrences, the following short note from the *Petroleum World* of March, 1912, by Dr. Ralph Arnold, may be quoted. The island to which it refers lay about a mile S 60° E. from the present one. Dr. Arnold said:—

"The first evidence of the disturbance which resulted in the formation of the new island (which, by the way, has been christened "Mud Volcano Island"), was the bubbling of water over Despatch Reef noted by fishermen on Tuesday, October 31st, 1911. On Friday evening of the same week (November 3rd) a decided agitation of the water was noticed in the same locality; and by Saturday morning, November 4th, the island had made its appearance. As described by Sergeant Wilkey, of the Colonial Police, who visited it on Friday afternoon, the island covered about an acre in extent, with a well-defined cone or crater, 20 to 30 feet high developed near the middle. Gas with a decided sulphur odour was bubbling from the ocean bottom on the flanks of the new shore.

"Shortly after Wilkey's return to shore the escaping gas caught fire, probably through the medium of sparks generated by the striking together

of stones ejected in the course of the eruption, which had now become violent. The flame from the burning gas rose to heights variously estimated at from 500 to 1000 ft., but soon died down.

"The writer's assistant, Mr. Geo. A. Macreedy, visited the island on November 8th, four days after the eruption, and found the island to embrace about 8¼ acres. Both Macreedy and the writer visited it on November 26th and made a detailed survey. The results of this survey, accompanied by a series of photographs, will shortly be published in one of the scientific journals. The island consists of mud and angular fragments of sandstone, shale and oil sand up to six inches or more in diameter. There were two well-defined craters and many minor ones emitting petroleum gas on both November 8th and 26th.

"These facts, taken in connection with the location of the island over one of the lines of disturbance along which are pronounced evidences of the presence of petroleum and petroleum gas, and on which are numerous gas and mud volcanoes, pitch cones, etc., offer conclusive evidence of the petroleum gas origin of the eruption. No volcanic rocks or evidence of recent volcanic action are known in Trinidad, and the origin of Mud Volcano Island has no connection whatever with any volcano or any form of volcanic action."

There seems to be some conflict of evidence about the exact time when it appeared, and its area. A photograph in the author's possession supports Wilkey's lower estimate, but may have been taken in the later stages of the island's disappearance; Dr. Arnold, who claims to have made a detailed survey, gives a figure that would require an average diameter of about 700 ft.; Waring gives 250 by 450 ft. as its original dimensions—*i.e.*, between two and three acres. On the whole, it seems probable that the earlier island was rather larger than the present one. The action was certainly more violent.

The Director of Public Works of Trinidad also reported as follows:—

"It was found that it marks the crest of the Southern Anticline, which was located by Mr. Cunningham-Craig, a little to the south of it . . .

"Surrounding the hard centre was a soft mud beach upon which have been thrown a number of interesting samples of rock, consisting chiefly of blue, grey and white sandstone, barren of oil. In addition there was found samples of gritstone, calcite, crystalline iron pyrites and a few samples of hard close-grained sand impregnated with oil.

"This mud volcano is of the same character as the other mud volcanoes on the same anticline in this district. The feature of these mud volcanoes is a great gas pressure, by which a large amount of mud, accompanied by fragments of rock, is hurled into the air to a considerable height . . .

"The fragments of oil sand present are samples from the Galeota series, which Mr. Cunningham-Craig gives as a dark sandstone, varying in hardness and character in different beds. The cover clay of the Galeota beds was found by Mr. Cunningham-Craig to be a stiff, bluish-grey, impervious rock; and it is of this rock that the whole of the island is formed, a large quantity of this rock having been ejected by the gas pressure and made into a thick pasty mass by the addition of the sea water.

"The presence of the calcite, iron pyrites and gritstone is an additional proof that the Galeota beds are the cause of the eruption of the island."

While we may not feel so confident as the Director of Public Works of either the source of the clay or the cause of the eruption,

it is interesting to note that his description of the rock fragments would apply very well to those found recently. The reference to the Galeota oil-sand is, however, obscure. Mr. Cunningham-Craig, whom he quotes, described the Galeota series in his report on the Mayaro-Guayaguayare Oilfield.* But in his description he made it clear that the oil-bearing rocks are either earlier or later than those of the Galeota group; he nowhere referred to the Galeota sandstones as dark-coloured, and there was no mention of their association with calcite, pyrites or grit. It is possible that some other report exists upon which these comparisons are based, but it has not been found.

No record exists, so far as can be determined, of other mud volcanoes in the sea. Those indefatigable enquirers, Wall and Sawkins, devoted an appendix of their report to the "Salses or Mud Volcanoes," and, as they make no mention of submarine eruptions, it is probable that none other has occurred in historic times.

Wall and Sawkins do, however, give a brief account of an event at Cedros in the later part of 1856 that is of interest. It appears that a roughly circular area of land, some 60 ft. across, was suddenly elevated about 15 ft. with some evolution of gas and violent agitation of the surrounding area to a distance of two or three hundred yards. This upheaval took place not far from the sea, and it seems probable that, had it actually been submarine it would have presented features not unlike the recent island.

The Islote Point volcanoes also present striking similarities to the present occurrences. They form an isolated elevation twenty to thirty feet high, with the sea on the South and the Los Blanquizales Lagoon on the North.

Except for the sand bank between the sea and the lagoon and the volcanoes themselves, the near by land must be practically at sea level, and a very slight depression would convert the volcano hillocks into islands. On the beach is an assemblage of rocks closely resembling those on the new island, and the mud of which the mounds are composed contains an older fauna than would be expected in this position. There is every indication that the whole mass is another example of a large mud flow, and the size of the rocks on the beach shows that considerable forces must have been in play at its inception.

Many other mud volcanoes are known on a line extending right across the south of the island in to the Guayagyayare district, but the eastern ones are of the more usual kind in which there is a continual gentle evolution of gas and mud. The violent

*Trinidad Council Paper, No. 25 of 1905.

intermittent manifestations seem to be confined to the western end of the structure as exemplified by the two islands, the Cedros upheaval of 1856 and possibly Islote Point.

The dissimilarities between the eastern and western volcanoes may be due to difference in thickness of cover. The development of the Palo Seco Oilfield has confirmed what the maps indicated, that the outcrops converge towards the mud volcano line as we go westwards. This convergence would be explained if we regarded the Palo Seco beds as lying on the north side of the structure with a westward plunge. But the effect of this would be that, in passing from east to west along the mud volcano line, we should encounter progressively younger beds, and the horizon in which the pressure originates would lie deeper. Greater pressure would, therefore, be needed to effect an outlet, but, once released, the action would be more intense.

The new mud volcano thus adds its quota to the evidence in favour of a fairly recent westward or south-westward tilt of, at any rate, a largish part of the South of Trinidad, a conception that will ultimately, I believe, help us to solve some of the more puzzling problems in the geology of the island.

DISCUSSION.

Mr. J. L. Harris said that he visited the island on the same day as the lecturer, and that his impression was that it was lenticular in shape. It was mainly composed of mud, but jagged rocks were found on it in a circle or ellipse over a narrow area a little above high water mark.

There was no evidence of rocks older than the St. Croix, but he saw blocks of soft St. Croix sandstone very readily identifiable as such. The height of the island was nine or ten feet above sea-level, and in the area at the western end considerable gas seepages were throwing the water six to eight feet into the air. The ejected blocks were as described, but he thought that many of them were much larger than had been described. He saw occasional blocks two to three feet across.

There was no other point he had to mention, except that in one part of the island there were many dead fish, killed apparently by the eruption. There were a good many foraminifera in the mud—ten or twelve species at least.

Mr. S. P. Richards said that he visited the island on January 28th, at which time its height above high water mark was 2 or 3 feet. Its dimensions were then 250 ft. by 110 ft.

There were many boulders in the mud up to 3 feet across, and he saw a laminated boulder which measured 2 ft. by 1 ft. by 9 ft. He also found pyrites which were characteristic of the St. Croix beds.

Mr. R. H. Skelton said that the description of the materials found on the island seem to compare exceedingly well with those found on the line of mud volcanoes in the Moruga district, with the exception of the Herrera sandstone, which he did not find in the Moruga district. That was the only point of variance as described by the lecturer with the main lines of the Moruga district.

Mr. W. G. Weeks, in reply, said : Mr. Richards, who surveyed the island a few days ago, has shown me a sketch plan on which its shape is lenticular rather than circular ; while, at one end, it is apparently continued by a small isolated elevation that did not quite reach sea-level.

When I visited the island there was a long line of mud-stained water running away to the west, which, we thought, might indicate the presence of a mud bank. As I have said, we took soundings all round, but could find no signs of elevation, so that, although no doubt lenticular describes the shape better than circular, the lens is not very elongated.

Mr. Harris visited the island only a few hours after I did and saw violent ebullition in the sea. Our party sailed completely round the island twice, once at about 100 yards distance in the launch and once only a few yards away in a dinghy. Neither time did we see any activity, so that this action is evidently intermittent.

The differences in estimates of height are probably due to the tide, but do not affect the elevation above sea-bottom.

Mr. Harris suggested that the rock fragments were concentrated around the central part of the island This, I think, applies only to the larger blocks There were many fragments, such as I have described, on the sand spit at the extreme edge of the water.

The Chair was then taken by Mr. J. S. Parker, M.A.

Washing Wells.

By A. Frank Dabell, M.I.Mech.E. (Member.)

It is suggested that wells should be washed before being put into production, and whilst the practice is common with some companies, it is questionable whether it is prompted by reason or merely the following of precedent.

For wells drilled under control, the replacement of mud by water is reasonably practised as the simplest method of reducing the weight upon the oilsand to induce flow.

The general idea, however, is that in course of rotary drilling, a coating of mud is thrown upon the face of the exposed strata which, in the case of an oilsand necessitates washing to give better release to contained oil.

It is unlikely that mud could be deposited in wells in a state of ebullition during the time of drilling into oilsands, but deposition is known to occur in stagnant wells.

Deposition, however, is a slow process, and it must be conceded that lesser amounts will be found with depth, therefore the thickness of this coating at the bottom of a well must be small, particularly as the rotary drill runs through oilsand at the rate of 1 foot per minute.

In the matter, therefore, of pumping clean water into a well to displace mud where oilsand is exposed, it is necessary to remember that whilst a majority contend that rotary mud will not enter sand, it is universally conceded that clear water will more readily do so, therefore, it is difficult to conceive why mud should be changed for water before the removal of liquid.

Assuming that a coating of mud might cover the face of an oilsand, its best method of removal should be that exemplified by the action of oil or gas forcing it from behind into, and discharging it from, the well rather than that of a current of clear water thinning and tending to press it further into the sand.

If the argument be adduced that the purpose of washing is to allow release of oil from sources which lack pressure sufficient to force entrance to the well, then its application would be doubly wrong, inasmuch as it entails putting oil sources under varying pressure into communication.

Where a series of oilsands are to be developed, it would be more logical to argue that mud should be in the first stage left covering their face, in order that under gradual reduction of pressure release be given their content in order of diminishing pressure.

DISCUSSION.

Mr. J. L. Harris said he thought that with wells drilled under control, to replace mud by water was reasonable practice, as it reduced the weight upon an oilsand and induced flow, and he knew from observation and results that it was efficient.

If mud will penetrate an oilsand water also will, and if mud was not penetrating water will wash away deposited mud from the face of the well and leave the oilsand exposed for better production.

Mr. H. D. Fletcher said he was satisfied that when "bringing in" new wells it was necessary, in most cases, to first replace the drilling mud with clear water by circulating before pulling the wash pipe, and particularly so in wells of low gas pressure.

This was supported by the fact that gas pressures which, when first encountered, would eject heavy mud, could often be controlled by the application of pump pressure without increasing the weight of mud subsequently brought back to production by circulating with clear water.

He had known instances of wells, which had not been washed, recording high pressures on the outside of the oil string while the inside had been swabbed and baled dry in efforts to induce production through the proper channel. The oil string had then been filled with clear water and circulated through the top perforations, after which the gas gained access to the inside of the oil string, ejected the water and commenced flowing oil.

A further objection to leaving heavy drilling mud behind the oil string was that the well may prove to be of low gas pressure necessitating swabbing or baling, both being operations that will clear the well of mud to bottom, but may also force a certain amount of mud back into the perforations and plug them.

The clogging of the passage of the oil string depended entirely on the diameter of the perforations or whether screen was used. He knew of a case where 90 mesh screen (·0065 in.) had not been washed, and took three days to induce flowing production inside the oil string, although 300 lb. pressure was recorded on the outside.

His experience was that ¼ in. diameter perforations might be cleared by low gas pressure wells without washing, but they may also permit the passage of too much sand; anything smaller necessitated washing with clear water or jet washing after the well was completed.

Mr. M. T. O'Connor said the practice in his field was to drill-in without using mud at all. They found that small shows were closed off by using mud, hence they cleared the mud-pits out and drilled into oil with clear water.

Mr. A. R. Crawford said that he found that washing low pressure wells with clear water improved production for the next few days. In Californian wells he had seen clear oil pumped down to get the sand and mud out of the well, which improved production by 50 per cent.

Lieut.-Col. H. C. B. Hickling said that the author declared the best method of removal of mud should be that exemplified

by the action of oil forcing it from behind and discharging it from the well. That seemed extremely reasonable, but unfortunately they could not get behind to force the mud on the wall of the well into the hole.

It seemed to him that the best method to practise for assisting this action must be to lighten the mud by changing it for water.

Mr. W. G. Weeks said he understood the author to say that the film of mud at the bottom of a well could only be very thin. But when cores are taken from a well, they are covered by a layer of mud at least half-an-inch thick and often much more. Yet the time taken for this to form could be only the few minutes that it needs to cut the core. He thought, therefore, that a considerable thickness of mud film might exist at the bottom of a well even if it had been in contact with the circulating fluid for only a short time.

Mr. A. Frank Dabell, in reply, said that one important feature underlying the discussion was the question as to whether mud does or does not enter sand. Papers upon high authority went to prove that whilst enormous pressure may be put on mud without forcing it into sandstone, when mud is changed for water, water enters freely. In any case it was universally conceded that water will enter sand quicker than mud, and that being so, one had to accept that when mud was taken from the face of an oilsand, water will enter and conceivably drive oil back.

Mr. Harris declared that in one area better results followed washing, but it would be interesting to know whether the wells were really washed or a heavy column of liquid changed for one lighter. Reduction of weight upon the face of an oilsand would assuredly encourage flow.

Mr. Harris : "The well is washed with clear water, for sometimes as long as three days with the wash-pipe in the oil string and the bit in the bottom of the hole."

The Author : "That is washing."

The Author, referring to the remarks made by Mr. Fletcher, said that almost any practice was justified where stagnation prevailed.

Mr. O'Connor's point that the use of clear water for drilling into oilsand gave better result in a certain area indicated gas pressure sufficient to resist entry of water in that particular area.

Referring to the question of Mr. Richards, if a gas and oilsand were opened at the same time and the pressure of the gas was higher

than that of the oil, he still thought it better for the oilsand to be covered during release of the gas until it had an equivalent pressure to that of the oil, when oil would be released automatically, for oil could not enter the well until the gas pressure had fallen below that of the oil.

Mr. Weeks had called attention to the heavy deposit of mud found upon cores at any depth, but the deposit on the face of an oilsand was limited by the diameter of the drilling bit, otherwise it would not be possible to withdraw the bit.

In reply to Col. Hickling, the Author said that whilst it was not possible to apply pressure at the back of the mud, it was possible to take advantage of the pressure there latent by reducing the weight of liquid in the well, either by reduction of the gravity of the liquid or by its removal by swabbing or bailing.

In some fields pressure in the sand was such that the explosive effect of the primary discharge was the only effort available for the removal of mud.

The question still remained as to whether it was a matter of precedent or sound practice to wash wells. He was still inclined to maintain that it was more often prompted by precedent than necessity. Instead of washing a well he thought it better to raise the bit above the oilsand and by pumping in clear water at that point to replace the mud above by water.

A vote of thanks was accorded the members of the Apex Club for the use of the building and the meeting terminated.

Communicated by Col. H. C. B. Hickling.

It appears to me, on further consideration, that the mud particles that are most effective in shutting off oil and gas are not those forming a plaster on the wall of the hole, but those that have actually penetrated into the sand, even though the distance penetrated be small.

Consider a hole in which the mud forms a plaster on the wall of the hole only.

This plaster, unless supported by the static head in the wall, would be easily displaced.

If the pressure in the oilsand was greater by but a few pounds, the mud plaster would be blown off. This plaster would also be washed away by circulating.

But in the case of a well where the mud particles have penetrated the sand, the condition would be entirely different. Every particle of mud would be supported by the surrounding particles of sand,

bridging conditions would occur and a very large difference between the pressure in the sand and the static head would be necessary before the mud particles could be ejected from the sand body.

The purely washing action of circulating would have no effect at all.

The only way to obtain the required difference in pressure is by decreasing the static head.

THE INSTITUTION OF PETROLEUM TECHNOLOGISTS, PERSIAN BRANCH.

ANNUAL REPORT, 1928.

General.—During the past year, the second since the formation of this branch, three meetings have been held at each of which one or more papers have been read. The interest shown by members of the branch has been maintained, as shown by the very generous response to the request for a local subscription to pay for the printing of the papers, and in addition we have acquired a number of new members and associate members.

Meetings.

MARCH 28TH, 1928.—"Heat Transfer with Particular Reference to Petroleum Refining Problems." H. W. Rigden.

NOVEMBER 21ST, 1928.—"A Review of Modern Refinery Engineering." R. S. Forbes. "Methods of Refining Sulphurous Oils." C. J. Wright.

DECEMBER 20TH, 1928.—"Motor Spirits." Dr. F. B. Thole.

A paper was also presented by Mr. C. S. Cleverly on the "Survey of New Oil Countries," but was not read owing to the author's departure on leave.

Members.—At the end of 1927 the total number of members of this branch were :—

Members	12
Associate Members	45
Associates	5
Students	3

At the end of the last year these members had become :—

Members	16
Associate Members	52
Associates	6
Students	3

There is, therefore, a net increase of :—

Members	4
Associate Members	7
Associates	1
Students	0

One member, three associate members, and one student have left, so that the actual increase in membership is :—

Members	5
Associate Members	10
Associates	1
Students	1

Committee.—Here it is necessary to record the overwhelming loss which we have suffered through the death of our Chairman, Mr. H. Y. V. Jackson, to whose energy and enthusiasm so very much of the success of this branch is due.

Balance Sheet.—This is self explanatory and requires no comment other than to mention the figure for stock of books on hand is an approximate one and has been estimated as closely as possible. In the absence of our Secretary it has not been possible to arrive at the exact number and value of the papers left on our hands. The amount involved, however, is a small one which he will rectify on his return.

INSTITUTION OF PETROLEUM TECHNOLOGISTS

INSTITUTION OF PETROLEUM TECHNOLOGISTS
(PERSIAN BRANCH).

Income and Expenditure Account for the year ended 31st December, 1928.

1928.	EXPENDITURE.	£	s.	d.	1928.	INCOME.	£	s.	d.
Dec. 31.	To Sundry Expenses	2	8	10	Jan. 1.	By Balance brought forward ..	18	19	4
	„ Annual Dinner		1	6	Dec. 31.	„ Subscription (Local)	20	10	0
	„ Depreciation on furniture and fittings	1	5	7		„ London contribution	25	0	0
	„ Free issue of publications to members	5	9	2					
	„ Balance	55	4	3					
		£64	9	4			£64	9	4

Balance sheet as at 31st December, 1928.

LIABILITIES.	£	s.	d.	ASSETS.	£	s.	d.
Excess of assets over Liabilities	55	4	3	Cash with A.P.O.C.	44	0	11
				Stock of books and literatures on hand ..	6	0	9
				Furniture and fittings £6 8 2			
				Less 20 per cent. depreciation .. 1 5 7			
					5	2	7
	£55	4	3		£55	4	3

Abadan, March 19th, 1929.

K. A. J. Sherwood,
for Refinery Accountant.

CORRESPONDENCE.

191, Rue St. Jacques,
Paris.

DEAR SIR,—In the February, 1929, issue of the Journal of your Institution we have noted the text of the speech made on December 11th, 1928, by Dr. Arthur Wade on "Madagascar and its Oil Lands."

We are extremely surprised that in a speech delivered and printed so recently no account should have been taken of the results of the official mission carried out by two of our number (Leon Bertrand and L. Joleaud) in 1923 in the Sakalave country, nor of those of the two missions, likewise official, of Mr. L. Barrabé in 1924 and 1926. The results of those missions have been published in scientific and technical periodicals, which cannot be ignored by a specialist (*Comptes-Rendus de l'Académie des Sciences de Paris, Bulletin de la Société Géologique de France, Revue Pétrolifère, Chimie et Industrie, Mémoires de la Société Géologique de Belgique, Bulletin des Mines de Madagascar*, etc.). In particular, the question of the bituminous sandstones and of petroleum in Madagascar formed the subject of a long discussion in 1924 before the Société de Chimie Industrielle, printed *in extenso* in its Review, *Chimie et Industrie*.

Now we wish to point out that the details given by Dr. Wade in his speech, as regards the French geologists and technicians, are all *prior to* 1923. Also, the geological and technical documentation of that speech leave a good deal to be desired; it is too often lacking in preciseness and completeness, and in our opinion is sometimes fantastical. We do not doubt that you will consider it necessary to pass on our remarks to the members of the Institution of Petroleum Technologists, so that they may know that they can, if they so desire, procure for themselves information upon the question of the geology and of petroleum in Madagascar from recent sources other than Dr. Wade's publication.

We are your very obedient Servants,

L. BARRABÉ,
Assistant Demonstrator in Geology at the Higher Normal School.

L. JOLEAUD,
Professor at the Sorbonne.

LEON BERTRAND,
Professor of Applied Geology at the Sorbonne.

Rest-a-While Place,
Pace,
Mississippi.

DEAR SIR,—I beg to acknowledge receipt of the criticism of my paper on Madagascar by French Geologists of the Sorbonne.

In the main I should criticise my paper for just those defects to which the French professors draw attention. I felt sure that something had been written as a result of these later expeditions of which I was aware, for I had the good fortune to meet members of one of them just as I was leaving Madagascar, but I failed to discover anything in the libraries I most frequent and, in consequence, asked a French bookseller to look into the matter and send me what he could find. What he sent did not help much and contained nothing mentioned in the letter of criticism. Knowing what has occurred sometimes in the past, I came to the conclusion that the reports were locked up in some Government office awaiting publication and planned to run over to Paris to see what I could find. Unfortunately, circumstances did not permit of this, and I made haste to complete the paper as it is before I left for field work abroad.

Admitting the imperfections in the paper, I think that these matters can be stressed too much, and that my friends rather misunderstand the objects of it, which were to place on record personal observations made in Madagascar and to give such an account of the country as would be of assistance to one of our members who might be called upon to go there for the first time. Moreover, the paper fills somewhat of a blank in our records, a blank which is more truly filled by the information conveyed in the letter of criticism with which I am dealing. For this reason, if for no other, I am glad that the paper was written and that it has provoked our friends into this reply.

I pass over the question of geological and technical documentation as rather impertinent. Quotations are made very largely from reports and papers in my own possession, and no pretence was made to supply a complete set of references. Those given were, I thought, sufficient for my purpose.

In the paper I express personal opinions and indulge in some geological speculation. Where I deal with personal observations and matters of fact I will maintain the accuracy of what I have written, but opinions and speculations are open to criticism and, in fact, may be regarded as fantastic by some who hold other opinions. To this I can have no objection whatever, though I may point out that the opinions and speculations of one generation, no matter how severely criticised they may be, often become the foundations for the advances made in succeeding generations.

I am, Sir, yours very truly, ARTHUR WADE.

REVIEWS.

The Analytical Principles of the Production of Oil, Gas, and Water from Wells. By Stanley C. Herold. California, Stanford University Press, 1928. $7.50.

This work has been correctly described as the theoretical mechanics of production from reservoirs.

The author having shown that all well-known physical laws are based upon the experiments of early investigators, combines these accepted laws with geometrical methods, and, by means of field or experimental data, evolves for the first time fundamental laws regarding the delivery of fluids from reservoirs.

Three distinct classifications of control are given and into one of these categories all oilfields belong.

The three groups are as follow :—

1. *Hydraulic Control.*—Pressure and rate of production remain constant during the course of production from the reservoir. This is an analogous condition to that of a water tank delivering its water with a head maintained at a constant level within it by the necessary inflow of more water.

2. *Volumetric Control.*—The pressure and rate of production decline during the course of production from the reservoir. This is analogous to a water tank delivering its water with a head declining in accordance with the production from it.

3. *Capillary Control.*—Pressure and rate of production also decline during the course of production. The decline here takes place in accordance with the characteristics of the "Jamin" capillary tube.

Reservoirs in Hydraulic and Volumetric control function according to hydraulic laws, in one case the pressure remaining constant and in the other case declining.

The outstanding feature of this treatise is the discovery of "Capillary control" and provides the solution for the frequent apparently erratic behaviour of many oil and gas wells.

The author has successfully based his theory here on the experiments of the French physicist, J. C. Jamin. The behaviour of the "Jamin" capillary tube is reproduced in porous formations when both liquid and gas are present. This action exists in a minor degree in Hydraulic and Volumetric control, but is predominant in the procedure designated by the author, "Capillary control."

The source of energy in reservoirs of "Capillary control" is due to gas pressure. Consequently the conservation of the gas in the reservoir, or the restoration of gas pressure, is beneficial in providing the necessary source of energy.

The new principles of production combined in the treatise are substantiated therein by mathematical proofs.

The present observations, taken on producing fields, should be amplified and plotted graphically. When these are considered with the mathematical analyses included in this treatise, information is provided the application of which enables the maximum efficient results to be obtained from the particular field.

It is essential that the type of control be established as early as possible in the life of a field, in order that development may proceed on correct lines.

It is obvious, for example, that it is useless to attempt the re-pressuring with gas of fields which fall into the classification of Hydraulic or Volumetric control and that it is equally beneficial to do so in the case of a field under Capillary control.

These broad examples may be extended in detail by utilising the information given in this book. Probably the most valuable scientific contribution to the problem of gas and oil production so far produced, this book will prove of immense value to Petroleum Production Engineers throughout the world.

C. DALLEY.

THE NAPPE-THEORY IN THE ALPS. Dr. Franz Heritsch. Translated by P. G. H. Boswell. London: Methuen & Co., Ltd., 1929. Pp. 228+ XXX., VIII, figs. 48. 14s. net.

Professor Boswell has rendered a great service to English speaking geologists by translating this most valuable study by Professor Heritsch, which should be read with close attention by all serious students of tectonics. In the opening chapters Professor Heritsch gives an excellent summary of the development of the Nappe-Theory from its tentative beginnings up to the present phase of far-reaching hypotheses, culminating in Rudolf Staub's great synthesis of the Eastern and Western Alps, a synthesis which, brilliant and stimulating as it is, admittedly runs far ahead of the proved facts and leaves many difficulties as yet unexplained. Professor Heritsch declares himself an opponent of the Nappe-Theory in its extreme form, and the greater part of the book is devoted to a critical examination of outstanding problems in the various parts of the Eastern Alps. He deals in turn with the East Alpine Nappes of Eastern Switzerland, the Silvretta, the Oetztal, the Hohe Tauern and the mountains which lie to the south and north of it, the Mur Alps, the Semmering, the Pre-Alps and the Northern Calcareous Alps, and the Southern Alps, and there is an important chapter on the problem of the Roots of the Alpine Nappes. In each case the exposition of the evidence is accompanied by a most useful statement of the differing interpretations made by various investigators, illustrated by numerous figures in the text.

There are many points of the first importance on which Professor Heritsch differs with the exponents of the Nappe-Theory in its extreme form. They have assumed that individual nappes extend for great distances along the strike, and have thus been obliged to introduce enormous heights and depths into their reconstructive sections. Again, they have assumed too readily that suites of rocks of similar facies belong to the same tectonic unit, even when separated by great distances; this view, together with the assumption that the rooting of the Helvetic nappes is typical of all Alpine nappes, has led to the postulation of enormous overthrusts in the Eastern Alps, which are very far from being proved. It has been assumed, further, that the formation of the Alps as a whole was effected by an orderly series of regional movements towards the north, and that movements in other directions were local effects of minor importance. On all these points, and many others, Professor Heritsch has much to say that is of absorbing interest. Taking the book as a whole, there emerges a strong case for supposing that the Alps, as we know them, were formed by a series of movements, each affecting a particular area, and each acting in a particular direction, and that, whereas in the Western Alps the later movements appear to have been, if one may use the word, "concordant" to the earlier movements, in many parts of the Eastern Alps they have not. It is a book that gives much food for thought.

It should be remarked that Professor Heritsch assumes in his readers a considerable knowledge of East Alpine geography and geology. Professor Boswell, in his Translator's Note, mentions a number of useful maps, in addition to which R. Staub's Tektonische Karte der Alpen (Zurich, 1923) will be found helpful. There is a large bibliography of more than 250 publications, and Professor Boswell has added a most useful glossary of tectonic and stratigraphical terms.

F. D. S. RICHARDSON.

LÉGISLATION MONDIALE DU PÉTROLE. J. Filhol. Paris: Recueil Sirey, 1929.

In a sense the name of this little work is a misnomer, for there is, of course, no world legislation on petroleum, or on anything else. But M. Filhol has undertaken the useful task of collecting in a single volume the laws of those nations which have legislated on this important subject, and it is hoped that his treatise may prove of value to the oil man, as well as to the lawyer. Modern as is the petroleum industry, the legislation governing it is younger still. At the outset most countries seem to have thought that a slight modification of their mining codes was all that was required to meet the emergency. New wine, however, goes ill in old bottles, and it was found that laws framed to control the search for minerals and their subsequent exploitation were little suited to the needs of the new industry.

While it is only since the beginning of the century that petroleum has forced its way into the forefront of world industries, it was during the Great War that its significance was first borne in upon all minds. Hence it is not surprising that the decade which has elapsed since the War should have been characterised by much hasty and ill-considered legislation. M. Louis Pineau (Directeur de l'Office National des Combustibles Liquides), who contributes a thoughtful preface to M. Filhol's book, remarks that petroleum legislation in different countries seems to have kept in view one or other of two main objects: (1) the encouragement of exploration and of the working of petroleum deposits when discovered; or (2) the protection of national resources against monopolisation by foreigners. And he slyly adds that the first tendency prevails in those countries which already produce petroleum on the grand scale: the second in those lands whose petroliferous wealth is largely in the region of devout hopes. Colombia and the Argentine are, no doubt, the States which M. Pineau has chiefly in mind when he says that "most of the countries of South America" have followed Mexico in nationalising their oil resources, but he might have spared a word of praise for Venezuela, whose enlightened policy has raised her in the short space of a few years to the second position among the oil-producing countries of the world.

The petroleum laws of the United States are based upon a fundamental rule of the American constitution, which recognises the surface owner as the owner of the subsoil, but this principle, though sound enough in itself, is undoubtedly responsible for the over-production which prevails, and it must therefore be limited in the general interest. M. Filhol reminds us that, so far back as 1919, the Texas legislature passed a law intended to secure the conservation of the petroliferous resources of the State. This law was fiercely impeached as an encroachment upon the sacred rights of the freeholder, but the High Court of Texas has declared its validity. If the example of Texas be followed by other States, conservation will become a uniform and practical policy. And, so far as the oil lands in the public domain are concerned, it is well to remember that "the Federal Government is by far the largest landed proprietors in the United States."

RICHARD BARNETT.

THE SALES ENGINEER. Gilbert Rigg. London: Mining Publications, Ltd., 1928. Pp. 112.

As stated in the preface "The Sales Engineer" was written by Gilbert Rigg from two points of view, the first being to show that Sales Engineering offers much scope for young engineers, and the second that it is of the utmost importance to both producer and consumer that the Sales Engineer should be a well trained man. There is much educational matter included in the twelve interesting and informative chapters of which the book consists. The

author's personal experiences, as narrated, emphasise the necessity for the Sales Engineer having a thorough knowledge of the commodities he is endeavouring to sell. This is a book which can be profitably read by the Student, the Producer, and the Consumer.

ASHLEY CARTER.

BOOKS RECEIVED.

DETERMINATION OF MOLECULAR WEIGHTS IN THE VAPOUR STATE FROM VAPOUR PRESSURE AND EVAPORATION DATA. Edward W. Washburn. U.S. Bureau of Standards Research Paper No. 53. U.S. Govt. Printing Office, Washington, D.C. 5 cents.

If the vapour pressure of a substance and the amount required to saturate, by aspiration, a measured volume of an indifferent gas are determined at the same temperature, the molecular weight in the gaseous state can be calculated. By using a reference substance of known molecular weight the volume of aspirated gas need not be measured and the quantities have small temperature coefficients. The method should have a high degree of accuracy and is applicable at temperatures lower than those commonly employed.

A NEW SEISMOMETER EQUIPPED FOR ELECTROMAGNETIC DAMPING AND ELECTROMAGNETIC AND OPTICAL MAGNIFICATION. Frank Werner. U.S. Bureau of Standards Research Paper No. 66. U.S. Govt. Printing Office, Washington, D.C. 15 cents.

The principles involved in the functioning of seismometers equipped for electromagnetic damping and electromagnetic and optical magnification are discussed and then used to develop an equation giving the relation between angular displacement of the galvanometer winding and linear displacement of the ground. This equation contains terms representing the galvanometer reaction upon the motion of the steady mass, an important point unless an unnecessarily large seismometer is used.

A procedure for the development of a seismometer design is illustrated by example in which the steady mass is about 500 g. The period may be recorded and the damping adjusted from the recording station and the magnification and its variation, in the range 2·5 to 60 secs., is substantially the same as given by an ordinary seismometer having a magnification for short-period displacements of 1,250, a period of 12·5 secs., and critical damping.

REPORT OF TEST BY THE DIRECTOR OF FUEL RESEARCH ON THE MACLAURIN PLANT INSTALLED AT DALMARNOCK GAS WORKS, GLASGOW. Dept. of Scientific and Industrial Research. London, H.M. Stationery Office. Pp. vi+26, with 7 figs. 9d. net. Postage extra.

A carbonising test was made on one unit of the plant, 100 tons of a Scottish coal being passed through in a period of five days. The yields per ton of dry coal were: Coke, 12·12 cwt.; tar, 17·8 gal.; gas spirit (crude), 1·5 gal.; gas, 33,160 cu. ft. (77·26 therms); liquor, 48·1 gal.; ammonium sulphate, 41·9 lb. The coke was well carbonised and contained 3·9 per cent. of residual volatile matter.